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AVENUE

Automated Vehicles to Evolve to a New Urban Experience

DELIVERABLE

D8.10 Second Iteration Sustainability assessment

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Acronyms

ADS	Automated Driving Systems
AM	Automated minibus
API	Application Programming Interfaces
AV	Automated Vehicle
BEV	Battery electric vehicle
CAPEX	Capital expenditure
CH4	Methane
CO	Carbon Monoxide
CO2	Carbon dioxide
EU	European Union
EV	Electric vehicle
GHG	Greenhouse gases
GNSS	Global Navigation Satellite System
H2020	Horizon 2020
ICEV	Internal combustion engine vehicle
ITS	Intelligent Transportation System (ITS)
LCA	Life Cycle Assessment
LiDAR	Light Detection And Ranging
MaaS	Mobility-as-a-Service
N20	Nitrous Oxide
NMVOC	Non-methane volatile organic compounds
NO	Nitric oxide
OPEX	Operational expenditure
pkm	Passenger-kilometre
PM	Particular matter
PRM	People with reduced mobility
PTO	Public transport operator
QALY	Quality-adjusted life-year
RF	Risk factor
SAE	Society of Automotive Engineers
SAEV	Shared automated electric vehicle
SAV	Shared automated vehicle
SDG	Sustainable Development Goals
SUMI	Sustainable Urban Mobility Indicators
SUMP	Sustainable Urban Mobility Plan
TCM	Total Cost of Mobility
TCO	Total Cost of Ownership
TDM	Travel Demand Management
V2I	Vehicle to Infrastructure
VKT	Vehicle Kilometer Travelled
WBCSD	World Business Council for Sustainable Development
WP	Work Package

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Executive Summary

This deliverable presents the second iteration of sustainability assessment, and has as objective to deepen the sustainable mobility indicators applied to the AVENUE demonstrator sites. This document is a continuation of the sustainability impact assessment, as presented in the D8.11 first iteration sustainability assessment. The sustainability assessment is part of AVENUE WP8, and aims to integrate and inter-relate the results of the social, environmental and economic impacts conducted on WP8 and to embed these results by applying the set of indicators for sustainability assessment of the automated minibuses (AM) within the AVENUE demonstrator sites.

The study is structured in five main sections. Section 1 introduces the context of AVENUE project and the deployment of pilot-tests of automated minibuses, seen as a complementary mode of transport to be integrated into public transport.

Section 2 contextualises the sustainability assessment, and places it into the context of the Sustainable Urban Mobility Plans (SUMP) and the broader WP8 framework. The section continues with an overview of the main results of the environmental, economic and social impact assessments.

Section 3 is the core of this deliverable and presents the sustainable mobility indicators. The section provides a detailed overview of the method and the indicators, and presents a first analysis of the AVENUE pilot sites. The results show differences in sustainability between the pilot sites, and point towards possible, necessary improvements of the automated minibus service in the pilot sites. The section concludes with indicating differences between the current sustainability position, and the AVENUE goals and vision for the future.

Section 4 provides an analysis of the impacts of the COVID-19 pandemic on urban mobility and AVENUE pilots in particular. It provides possible solutions to make the automated minibus service COVID-proof. An example hereof is the possibility to include an electronic query into the app during ordering the minibus, that will make sure that the bus is only used by persons that can either provide a negative test result or are vaccinated.

The final section of this deliverable, section 5 provides a roadmap to the next, final sustainability deliverable and provides intermediate conclusions.

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1 Introduction

AVENUE aims to design and carry out full-scale demonstrations of urban transport automation by deploying, for the first time worldwide, fleets of Automated minibuses in low to medium demand areas of 4 European demonstrator cities (Geneva, Lyon, Copenhagen and Luxembourg) and 2 to 3 replicator cities. The AVENUE vision for future public transport in urban and suburban areas is that Automated vehicles will ensure safe, rapid, economical, sustainable and personalised transport of passengers. AVENUE introduces disruptive public transportation paradigms on the basis of on-demand, door-to-door services, aiming to set up a new model of public transportation by revisiting the offered public transportation services and aiming to suppress prescheduled fixed bus itineraries.

Vehicle services that substantially enhance the passenger experience, as well as the overall quality and value of the service, will be introduced, also targeting elderly people, people with disabilities and vulnerable users. Road behaviour, security of the Automated vehicles and passengers' safety are central points of the AVENUE project.

At the end of the AVENUE project four-year period, the mission is to have demonstrated that Automated vehicles will become the future solution for public transport. The AVENUE project will demonstrate the economic, environmental and social potential of Automated vehicles for both companies and public commuters while assessing vehicle road behaviour safety.

1.1 On-demand Mobility

Public transportation is a key element of a region's economic development and the quality of life of its citizens.

Governments around the world are defining strategies for the development of efficient public transport based on different criteria of importance to their regions, such as topography, citizens' needs, social and economic barriers, environmental concerns and historical development. However, new technologies, modes of transport and services are appearing, which seem very promising to the support of regional strategies for the development of public transport.

On-demand transport is a public transport service that only works when a reservation has been recorded and will be a relevant solution where the demand for transport is diffuse and regular transport is inefficient.

On-demand transport differs from other public transport services in that vehicles do not follow a fixed route and do not use a predefined timetable. Unlike taxis, on-demand public transport is usually also not individual. An operator or an automated system takes care of the booking, planning and organisation.

It is recognised that the use and integration of on-demand Automated vehicles have the potential to significantly improve services and provide solutions to many of the problems encountered today in the development of sustainable and efficient public transport.

1.2 Fully Automated Vehicles

A self-driving car, referred to in the AVENUE project as **a Fully Automated Vehicle** (**AV**), also referred to as Autonomous Vehicle, is a vehicle that is capable of sensing its environment and moving safely with no human input.

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The terms *automated vehicles* and *autonomous vehicles* are often used together. The Regulation 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles defines "automated vehicle" and "fully automated vehicle" based on their autonomous capacity:

- An "automated vehicle" means a motor vehicle designed and constructed to move autonomously for certain periods of time without continuous driver supervision but in respect of which driver intervention is still expected or required
- "fully automated vehicle" means a motor vehicle that has been designed and constructed to move autonomously without any driver supervision

In AVENUE we operate ***Fully Automated minibuses for public transport***, (previously referred to as Autonomous shuttles or Autonomous buses), and we refer to them as simply *Automated minibuses* or *the AVENUE minibuses.*

In relation to the SAE levels, the AVENUE project will operate SAE Level 4 vehicles.

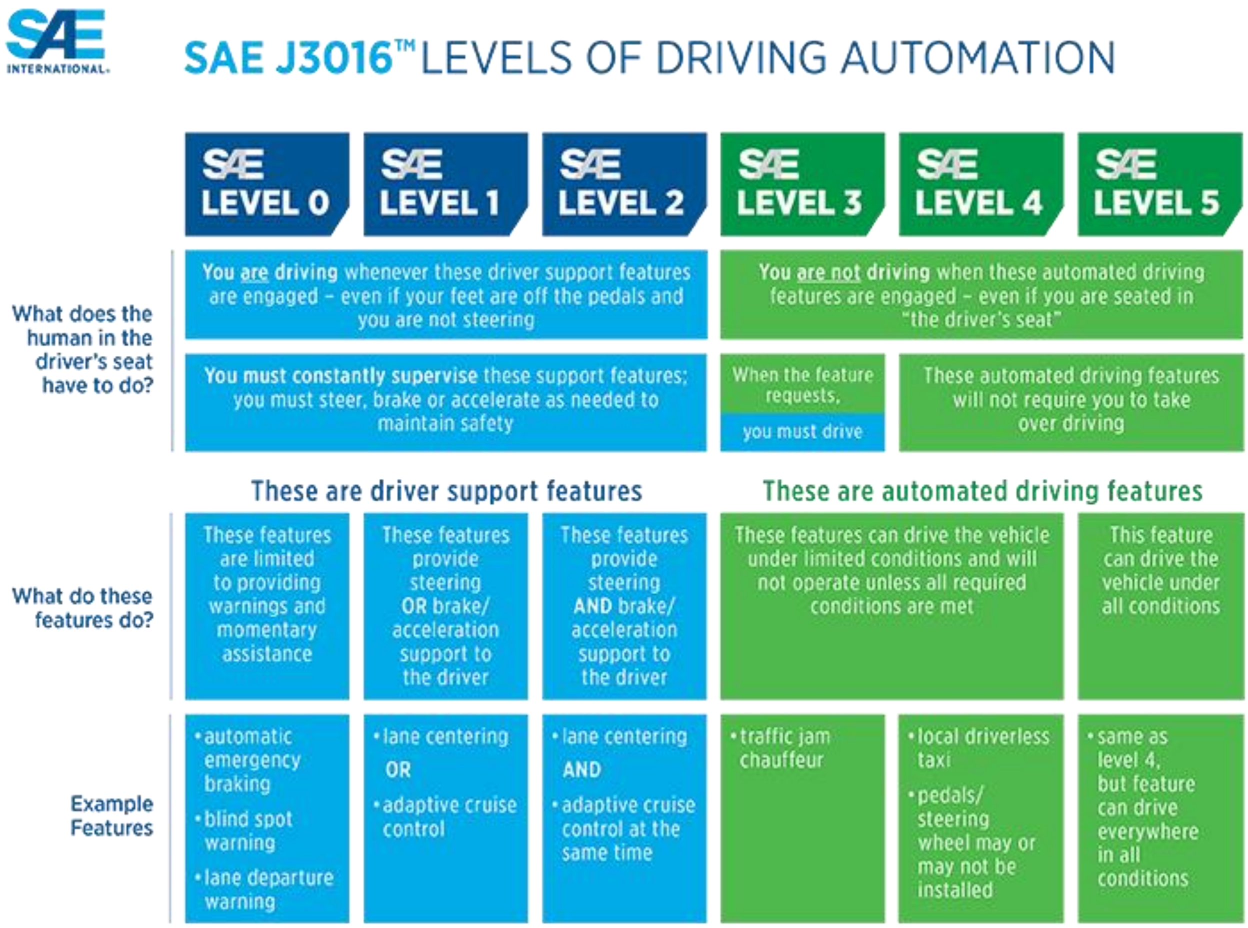

Figure 1. SAE Levels of driving automation

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1.2.1 Automated vehicle operation overview

We distinguish in AVENUE two levels of control of the AV: micro-navigation and macro-navigation. Micro navigation is fully integrated into the vehicle and implements the road behaviour of the vehicle, while macro-navigation is controlled by the operator running the vehicle and defines the destination and path of the vehicle, as defined the higher view of the overall fleet management.

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For micro-navigation, Automated Vehicles combine a variety of sensors to perceive their surroundings, such as 3D video, LiDAR , sonar, GNSS, odometry and other types sensors. Control software and systems, integrated in the vehicle, fusion and interpret the sensor information to identify the current position of the vehicle, detecting obstacles in the surrounding environment, and choosing the most appropriate reaction of the vehicle, ranging from stopping to bypassing the obstacle, reducing its speed, making a turn etc.

For the Macro-navigation, that is the destination to reach, the Automated Vehicle receives the information from either the in-vehicle operator (in the current configuration with a fixed path route), or from the remote-control service via a dedicated 4/5G communication channel for a fleet-managed operation. The fleet management system takes into account all available vehicles in the services area, the passenger request, the operator policies, the street conditions (closed streets), and send route and stop information to the vehicle (route to follow and destination to reach).

1.2.2 Automated vehicle capabilities in AVENUE

The Automated vehicles employed in AVENUE fully and automatically manage the above-defined micro-navigation and road behaviour in an open street environment. The vehicles are automatically capable to recognise obstacles (and identify some of them), identify moving and stationary objects, and Automatically decide to bypass them or wait behind them, based on the defined policies. For example, with small changes in its route the AVENUE shuttle is able to bypass a parked car, while it will slow down and follow behind a slowly moving car. The AVENUE vehicles are able to handle different complex road situations, like entering and exiting round-about in the presence of other fast running cars, stop in zebra crossings, communicate with infrastructure via V2I interfaces (ex. red light control).

The shuttles used in the AVENUE project technically can achieve speeds of more than 60Km/h. However, this speed cannot be used in the project demonstrators for several reasons, ranging from regulatory to safety. Under current regulations, the maximum authorised speed is 25 or 30 Km/h (depending on the site). In the current demonstrators, the speed does not exceed 23 Km/h, with an operational speed of 14 to 18 Km/h. Another, more important reason for limiting the vehicle speed is safety for passengers and pedestrians. Due to the fact that the current LIDAR has a range of 100m and the obstacle identification is done for objects no further than 40 meters, and considering that the vehicle must safely stop in case of an obstacle on the road (which will be “seen” at less than 40 meters distance) we cannot guarantee a safe braking if the speed is more than 25 Km/h. Note that technically the vehicle can make harsh break and stop with 40 meters in high speeds (40 -50 Km/h) but then the break would too harsh putting in risk the vehicle passengers. The project is working in finding an optimal point between passenger and pedestrian safety.

Due to legal requirements a **Safety Operator** must always be present in the vehicle, able to take control any moment. Additionally, at the control room, a **Supervisor** is present controlling the fleet operations. An **Intervention Team** is present in the deployment area ready to intervene in case of incident to any of the mini-busses.

1.3 Preamble

This deliverable presents the AVENUE sustainability assessment, within the scope of WP8, the AVENUE sustainability assessment integrates the environmental, economic and social assessment of the trials of AVENUE. It adopts an interdisciplinary approach to better conduct different analyses. It also helps to better understand the complexity of deploying a new form of mobility in urban areas and as part of the

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transportation system. The goal is to implement new mobility solutions that are beneficial for the city and complementary to public transport. For instance, the results of the social and economic assessments provide important insights to predict scenarios for automated vehicles and calculate direct and indirect costs. Even more, the Life Cycle Assessment (LCA) is a source of environmental data that could be used to calculate environmental externalities. In addition, the findings from the social, environmental and economic impact assessments are embedded in the indicators for sustainability assessment. To better understand the different connections, the AVENUE assessment framework is presented in Figure 2.

The framework describes three major axes: first the data input, methods and analysis; second the social, economic, environment and sustainability assessments, and the connections with other Work Packages tasks.

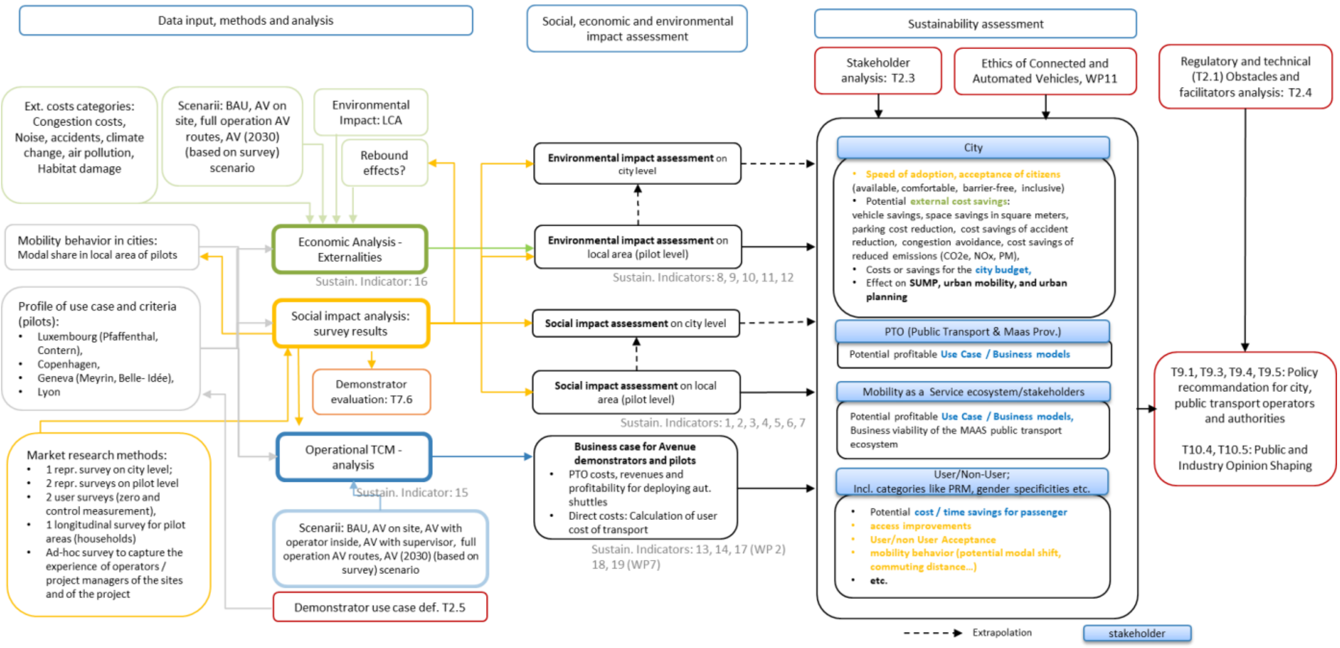

Figure 2. Framework for WP8 AVENUE sustainability assessment

Chapter 2 of this deliverable contextualises the sustainability assessment and places it into the context of the Sustainable Urban Mobility Plans (SUMP). SUMPs are a cornerstone of European transport policy and are an important planning tool for municipalities and authorities in the EU. After an introduction of the SUMP concept and a critical review of the automated minibus service in the wider SUMP context, this section depicts the alignment of the AVENUE project and the SUMP concept. This alignment is constructed through a mutual embracement of new and alternative modes of transport and new concepts as Mobility as a Service (MaaS), integrated and shared mobility, multi and intermodal mobility. In a second major part of chapter 2, we contextualise this deliverable in the broader WP8 framework and will conclude with an overview of the main results of the environmental, economic and social impact assessments.

The third chapter details the methodology and presents intermediary results of the set of indicators for sustainability assessment of the automated minibuses according to the pilot sites. The fourth chapter brings considerations about the impacts of the Covid-19 pandemic on mobility, and on the deployment of automated minibuses. The fifth chapter presents an outlook for further research on the sustainability assessment of future mobility systems.

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2 The AVENUE approach to sustainability assessment

This chapter outlines the AVENUE sustainability assessment, starting with central concepts and the applied framework. In section 2.2 an overview is provided of the main results of the other tasks of AVENUE WP8: insights from the environmental impact assessment, the economic impact assessment and the social impact assessment.

2.1 Concept and framework for assessing and planning sustainable urban mobility

2.1.1 SUMP as a framework

The concept of the Sustainable Urban Mobility Plan (SUMP) aims at a 'new planning paradigm' in mobility, which comprehends a shift from planning for motorised roads and infrastructure to planning for people (Arsenio et al. 2016). SUMP's approach has been widely recognised, targeting sustainable and integrative planning processes to deal with the complexity and dynamicity of urban mobility (Eltis 2020). Hence, it embraces new modes of transport, e.g. micro-mobility, automated and connected vehicles, and new concepts as Mobility as a Service (MaaS), shared mobility and so on.

The concept of SUMP comprehends the integration of all modes of transport, public and private, motorised and non-motorised and a long-term planning vision. It targets to improve mobility accessibility, sustainability and citizens' well-being (European Commission 2013).

SUMP is defined as:

> *"a strategic plan designed to satisfy the mobility needs of people and businesses in cities and their surroundings for a better quality of life. It builds on existing planning practices and takes due consideration of integration, participation, and evaluation principles." (Rupprecht Consult 2019)*

And it is guided by eight principles (Chinellato and Morfoulaki 2019):

1) Aim of sustainable mobility for the 'functional urban area.';
2) Assessment of current and future performance;
3) Long-term vision as well as a clear implementation plan;
4) Development of all transport modes in an integrated manner;
5) Cooperation across institutional boundaries;
6) Involvement of citizens and relevant stakeholders;
7) Arrangements for monitoring and evaluation;
8) Quality assurance.

Further, SUMP provides general guidelines for planning and implementation. It is composed of four main phases: i) Preparation and context analysis; ii) Strategy development; iii) Measure planning; iv) Implementation and monitoring.

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SUMP has been implemented in a number of cities and countries and in diverse settings. For instance, in the city of Koprivnica, Croatia, the municipality carried out a status analysis of its mobility situation; for this, an extensive consultation process engaged a range of stakeholders and a public survey (Mobility Plans n.d.). In Cambridgeshire, UK, the Local Transport Plan (LTP) 2011 – 2026 defined indicators and targets to monitor progress towards the plan's objectives, which were aligned with the long-term strategy for transport (ibid).

Mück et al. (2019) describe the living labs as an innovative approach to foster sustainable mobility planning in Munich. Such living labs aim to demonstrate innovative solutions on mobility, to provide user experiences and to reduce potential gaps between long term urban planning and the current development of mobility in the city (ibid).

Sampaio et al. (2020) carried out an economic and environmental analysis of measures from a SUMP in a small-sized city. The study compared the transport emissions and external costs of the baseline scenario with the status after the SUMP measures were implemented. The measures consisted of (M1) promoting cycling, (M2) modernisation of the local fleet, (M3) trucks logistic optimisation. According to the study, all measures presented a potential to reduce emissions, in particular the modernisation of the local fleet, with a potential reduction of CO_2 emissions by 9% and the reduction of external costs by 11%.

The study from Arsenio et al. (2016) reviewed a sample of forty case studies of SUMPs in Portugal, focusing on climate change goals and equity issues on accessibility. The main findings point that SUMP guidelines remain very broad and general, and there is an absence of specific guidance. For instance, there are gaps of guidance on methods to account for GHG emissions and monitoring indicators to measure the progress in different issues.

Such examples illustrate the SUMPS adoption and implementation in different phases: decision and planning, developing vision and strategies with stakeholders, setting targets and indicators, assessing the impacts of measures. Although, as mentioned by Arsenio et al. (2016), the next SUMP generations may address more specific guidance and methods to strengthen SUMP's implementation.

2.1.2 SUMP concept and the AVENUE project

The AVENUE project aims at deploying automated minibuses as an innovative and safe mobility solution to strengthen the public transport system of European cities. The automated minibus is electric and shared, and it is expected to improve accessibility, attractiveness and environmental performance of public transport (flexible on-demand, door-to-door services) to fill gaps in mobility and foster multi and intermodal mobility. The scope of the project also aims to critically assess the impacts of the introduction of these new technologies in the urban mobility system. The assessments investigate the potential environmental and climate emissions impacts, social acceptance of users and potential users, business model scenarios and economic impacts, safety and security issues, the development of regulations, standards and policies for AVs.

AVENUE project and the SUMP concept are aligned by embracing new and alternative modes of transport and new concepts as Mobility as a Service (MaaS), integrated and shared mobility, multi and intermodal mobility. Such innovations could support the future shift from private car and individual trips to on-demand public transport and shared rides.

Furthermore, the AVENUE social, environmental and economic impact assessments will provide key findings to guide the integration and implementation of AV in the urban mobility system while endorsing the sustainable planning, strategies and goals of cities. The assessments studies are important to support a long-term vision, design and planning of mobility. Although the pilot projects are deployed on a small

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scale and with a technological focus, aspects of being strengthened are the citizens' participation (e.g. citizen forums, discussions), as well as the active participation and partnership with the local municipality. Moreover, the integration of automated minibuses in public transport has to be done accordingly to the specificities of each territory, the different mobility needs, aiming to cover real gaps in mobility to a real contribution to better accessibility, affordability and environment-friendly mobility. Further, the outcomes from the sustainability assessment and other WP8 tasks are building blocks for WP9, which will deliver strategies, recommendations and roadmap for AVs on public transport coupled with Intelligent Transort Systems (ITS) and MaaS.

Finally, by aiming a transition towards a greener and sustainable transport, it is crucial that AVs deployment to be consistent with the Sustainable Development Goals (SDG's), namely, SDG 9 targeting to build resilient infrastructure and foster innovation, SDG 11 on sustainable cities and communities and SDG 13 Climate Change (United Nations 2015).

2.1.3 AVENUE sustainability assessment framework

Automated minibuses for public transport are expected to contribute to sustainable urban mobility. By combining automated, connected, shared, and electric technologies, the automated minibuses could improve transport accessibility, efficiency and reduction of greenhouse gases (GHG) (Jones and Leibowicz 2019). They have the potential to play a role in a shift from vehicle ownership to shared mobility services (Shaheen and Chan 2016) and to reduce transport externalities (Lim and Taeihagh 2018). Nonetheless, one cannot take for granted that the deployment of innovation and new technologies per se will contribute to sustainable mobility. It rather depends on certain premises, planning and policies to frame the automated minibuses deployment.

The study from Taiebat et al. (2018) points main gaps concerning connected and automated vehicles impacts; for instance, the net effect of AVs technology on energy consumption and emissions in the long term remains uncertain. In addition, the broader society-level impacts and behavioural changes associated with AVs are also unclear. The study highlights that the 'synergetic effects of vehicle automation, electrification, right-sizing, and shared mobility are likely to be more significant than anyone isolated mechanism'.

AVs, especially for private use, could lead to an increase in vehicles kilometres travelled (VKT), reductions of the public transport and slow modes share (Soteropoulos et al. 2019). Whereas shared automated vehicles (SAV), when considering a high share, could reduce the number of vehicles for the current travel demand, result in less parking and more space in the cities (ibid). Yet, it is worth noting that the results on impact assessment for AVs strongly dependent on model assumptions (Soteropoulos et al. 2019).

The integration of automated minibuses into the public transport of European cities also raise questions regarding their potential benefits and critical points to contribute to the sustainable urban mobility plan (SUMP) and goals towards sustainable mobility of the cities.

Hence, the goal of the sustainability assessment is to integrate and inter-relate the results of the social, environmental and economic impacts conducted on WP8 and to embed these results by applying the set of indicators for sustainability assessment of the automated minibuses within the AVENUE demonstrator sites. The SUMP and externalities concepts are also building blocks for the sustainability assessment. In addition, the study reports the impacts of Covid-19 on mobility and the deployment of the automated minibuses within AVENUE.

Figure 3 summarises the research questions guiding the study, the methods to address those questions and respective chapters.

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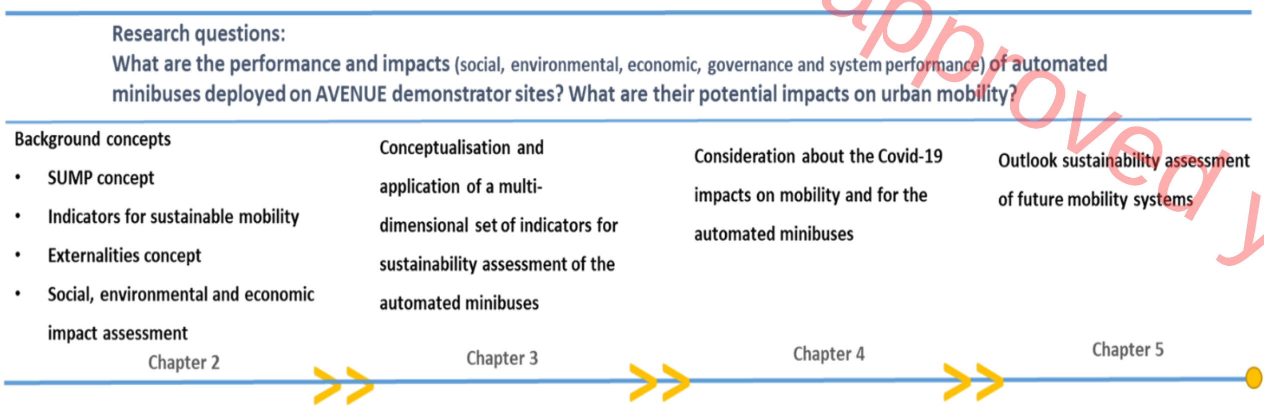

Figure 3. The AVENUE sustainability assessment approach

The next subsections summarise the main social, environmental and economic impacts associated with automated minibuses (WP8) are summarised. The analysis is grounded on real-world data from the pilot test in the four European cities: Geneva, Lyon, Luxembourg and Copenhagen.

2.1.3.1 Indicators for sustainable mobility assessment

By aiming to achieve sustainable mobility, indicators are used to measure performance and progress towards established goals and objectives (Litman, 2007). Urban sustainability indicators are fundamental to support target setting, performance reviews and to enable communication among the policymakers, experts and general public (Shen et al. 2011; Verbruggen, H., Kuik O. 1991).
Hence, a set of indicators is applied for the sustainability assessment of the deployment of the automated shuttles in AVENUE pilot sites. The set of indicators was presented on D8.11 First Iteration Sustainability Assessment and the final version on the article of Nemoto et al. (2021).
Chapter 3 details the indicators and presents preliminary indicators' radar for the pilot sites of Groupama (Lyon), Contern (Luxembourg), Pfaffenthal (Luxembourg), Nordhavn (Copenhagen) and Ormoya (Oslo).

2.1.3.2 Externalities concepts and applications to support sustainable mobility

Mobility Externalities represent the costs incurred by a third party and not borne by transport users. The negative externalities could help draft targeted public policies (i.e., urban planning and urban mobility policies) that addresses the negative effects of the transportation system (Chatziioannou et al. 2020). Using external cost estimates as a part of cost-benefit analysis help weigh in the benefits and drawbacks of introducing new policies or new forms of mobility such as automated minibuses (Jochem, Doll et Fichtner 2016). This tool relies on interdisciplinary assessment to monetise impacts such as air pollution, climate change, accidents, and congestion (European Commission 2003). These impacts have always been associated with the transportation system. The development of such systems plays an important role in government policies because transportation planning has overlapping effects on society. Thus, it should reflect potential negative externalities (Shiftan, Kaplan et Hakkert 2003). The internalisation of externalities leads to increased efficiency and reduction of negative effects of transportation. According to van Essen H.P. et al. (2008), the internalisation of these effects means incorporating them to transport users' decision-making process.
Policymakers seek to reduce the reliance on ICEV (Fagnant and Kockelman 2015; Anderson et al. 2014; Dacko and Spalteholz 2014; Gärling and Schuitema 2007; Mourad et al. 2019; World Business Council for

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Sustainable Development 2015; TUMI 2021; European Commission 2021). The introduction of new modes of transport lead by electrification and automation technology presents a potential shift from traditional and unsustainable mobility. The study of externalities leads to customised policies that address the specification of these technologies and the context of deployment (Buehler et al., 2017). The assessment depends on planning potential future scenarios of deployment and estimating the avoidance costs (of externalities), which present imputed costs of limiting the environmental damage by reducing the use of individual transport (OECD 2001; United Nations 1997). The avoidance costs (or savings) indicate if the specific scenario is recommended for future mobility. The scenario is imagined based on driving forces such as the development of the AV technology, the existing urban and mobility policies, and the modal shifts due to the minibuses (Krueger and Rashidi 2016). Thus, the externalities could orient policymakers towards the scenario to adopt and how to further reduce the environmental deterioration of the transport sector. For instance, travel demand management (TDM) could rely on these insights.
The TDM measures are:

- Measures with push effects: to restrict the travel demand for individual vehicles such as car limited zones, car bans, speed limits, and road pricing
- Measures with pull effects: to attract more users for public transport and active mobility such as park and ride, more frequent services, and biking lanes
- Measures with push and pull: focuses coordinated actions to reduce individual mobility and promote sustainable mobility, such as raising awareness through marketing campaigns and reassignment of road space (TUMI 2018). Other measures could be increasing mobility attractiveness by higher flexibility, on-demand services, and lower costs.

Moreover, other internalisation measures could help counterbalance the external costs. Trading emissions limits greenhouse gas emissions, such as the Cap & Trade scheme, where a limit is set for emissions with tradable emission rights. Also, Policy Packaging is a way to set taxes to balance the external costs like fuel taxes and road pricing. Another measure is the use of revenues (e.g. from policy packaging taxes) to make users accountable for the externalities they produce. The revenues will be directed towards new infrastructure or improving public transport services as long as the pricing reform is conducted to increase efficiency and equity and is public acceptable (van Essen H.P. et al. 2008).

2.2 Insights from AVENUE research

As part of the WP8, the sustainability assessment considers the main findings stemming from the three pillars and their deliverables[1]:

- 8.1 Environmental impact assessment, which presents the Life Cycle Assessment of the automated minibuses and their potential impacts considering different scenarios.
- 8.2 Economic impact assessment, based on Total Cost of Ownership (TCO) and Total Cost of Mobility (TCM) approaches, and externalities cost calculations.
- 8.3 Social impacts assessment, which conducts assessments based on surveys with potential users and users, investigates social acceptance of the AM, service attractiveness, user experience and willingness-to-use.

As the fourth pillar, the 8.4 Sustainability assessment conceptualises (as presented in the D8.11 First Iteration Sustainability Assessment) and applies a set of indicators to assess the social, environmental, economic, governance, and technical impacts of the automated minibuses. The sustainability assessment

[1] AVENUE deliverables and publications at https://h2020-avenue.eu/public-delivrables/

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also comprises the SUMP concept related to automated driving and the automated minibuses for public transport.
Next, the main findings from the social, environmental and economic impact assessment are summarised.

2.2.1 Main findings from the environmental impact assessment

The Life Cycle Assessment study pointed to the following main parameters influencing the environmental and climate impact of the automated minibuses: electricity mix for the use phase and component production, vehicle lifetime, vehicle lifetime mileage, and the average passenger occupancy (Viere et al. 2021).
The climate impact of the current demonstrator cases is significant in the manufacturing phase. However, when considering future use cases (with increased vehicle lifetime, increased total mileage, etc.), the use phase becomes the most important climate contributor. This is due to the passenger-kilometre (pkm) contribution of the manufacturing, assembly and end-of-life phase diminishes due to higher overall pkm. Further, within an ideal future use case scenario, those phases gain in importance because of increased vehicle energy efficiency and the use of renewable electricity for charging it.
The comparison of the automated minibuses with other modes of transport shows that the climate impacts of the current demonstration cases (pkm) are significantly lower than those of a diesel bus but much higher in comparison to most other means of public transport. However, in the near future, the automated minibuses are expected to perform better than all other means of transport at off-peak and better than all individual vehicles at average operation. Compared to other public transportation vehicles' peak and average operation, the automated minibuses are on similar levels.
One point to be further explored is the energy consumption impacts of the automated minibuses by considering that AVs have a higher energy consumption compared to conventional vehicles (due to sensors, communication, digital infrastructure, etc.). On the other hand, energy savings from connectivity, optimisation of fleet operations, intersection V2I, platooning, eco-driving could offset the vehicle energy consumption.

2.2.2 Main findings from the social impact assessment

This section summarises the main findings from AVENUE social impact assessment that aims to assess the mobility needs, social acceptance of and attitudes towards the automated minibuses and their services (Korbee et al. 2021). The intermediate findings below are based on a qualitative study among potential users (n=8), a qualitative study among safety operators in the shuttles (n-8), a quantitative survey among potential users (n=871), and a quantitative survey among actual users (n=68) of the automated minibus survey in Copenhagen.
Currently, there is no acute need for the complete substitution of current public transport offers nor for the other transport means (i.e private cars) in the perception of citizens. The automated shuttles could provide an additional service, to increase the use of public transport by providing a solution for the first-and-last mile. The automated minibuses are expected to offer higher temporal and local flexibility, less waiting time, and cheaper transportation offer. Therefore, the automated minibus is primarily perceived as a possible solution for the current gaps in public transport offers, but only if it highly fulfils these benefits.
The majority of the potential users interviewed in the AVENUE cities have not yet taken a clear position towards automated minibus, but they tend towards a positive, receptive (goodwill) attitude. Overall, there is a high willingness to use the automated minibus service. The results show that willingness to use the automated minibuses increases if an on-demand service is provided and that people are only interested

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in changing their mobility behaviour if it provides additional temporal and spatial flexibility. It is however, not clear whether a 'full' on-demand, door-to-door service is necessary to increase the acceptance and use of the automated minibus service. This is a topic that is currently assessed in the social impact assessment.

The user survey shows a high satisfaction with the provided service in Nordhavn, Copenhagen. However, the majority of users did use the automated minibus at random, motivated by spontaneous interest and curiosity. The use is rarely planned. Thus, even though users are satisfied and state that they are willing to use the service again, the lack of an acute need for better alternatives prevents regular use. However, even attracting 'random' user in the pilot sites, has a positive effect on the acceptance of automated minibus services, as real experience in the automated minibus has a positive effect on the trust in the system. A comparison of the results of the quantitative survey with potential users and the quantitative survey with users in Nordhavn (Copenhagen) shows that user experience is an important factor to reduce the perceived concerns and to increase acceptance of the automated minibus.

2.2.3 Main findings from the economic impact assessment

Based on the results presented in the second iteration of the economic deliverable and on the WP2 stakeholder analysis, in a first step, the economic impact assessment defines, describes, and analysis four business scenarios of mobility systems for the integration of the automated minibuses:

i) PTO centred ecosystem: focuses on public transportation mobility system.

ii) Automotive centred ecosystem: focuses on the private car and indivisual mobility.

iii) New Mobility Provider centred Ecosystem: considers the potential effects of robotaxis as a car-sharing fleet on mobility as well as cities.

iv) Customer/Citizen Centred Intermodal MaaS centred Ecosystem: focuses on the automated minibuses in an integrated transport system and MaaS, it is called AM in ITS. In this context, the AM is deployed for the first and last miles and to fill mobility gaps.

The first (medium term) and two last scenarios specifically (long term perspective) are the backbone for the WP9 analysis and will be deepen later.

In a second step, the Internal costs simulation tool (EASI-AV© - available on the Avenue website[2]) was designed with the objective of helping policy makers in cities, regions, Public Transport Operators (PTOs), and others interested stakeholders that may wish to implement services with Autonomous Vehicles for collective transport (e.g.: private corporate sites or university/hospital campuses). The tool is composed of independent but complementary analysis, that can provide decision-makers with: a fleet size dimensioning tool; comparative service cost analysis; comparative local external cost analysis; total cost of the service; comparative revenue analysis; net present value calculation.

The preliminary results show that the cost per passenger/km for the current demonstrators are still higher in comparison to traditional public transport offerings. The AVENUE average calculated price is 1,07 Euros per passenger/km. This result endorses the findings by Henderson et al. (2017) in their feasibly study for a shuttle-service trial in Ohio State University Campus, where the authors also concluded that the automated shuttle is indeed currently not cost-effective relative to traditional buses.

However, as technology and legislation evolve, it is expected that in the coming years, an on-board safety driver will no longer be needed (which will drastically reduce the costs with personnel), among other expected costs reduction. This is in line also with the findings of the social assessment as it shows passengers are willing to use the automated minibuses without safety-drivers.

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[2] EASI-AV©: https://h2020-avenue.eu/avenue-economic-calculator/ Accessed on June 30th, 2021.

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Current economic affordability barriers for the transport operators to deploy the automated minibuses as presented in the economic deliverable are related to (Antonialli et al. 2021):

- elevated costs with feasibility studies and legal;
- required investments on infrastructure works and road adaptations (e.g. V2I intersections, adaptations of roads and traffic signs, adaptation and construction of stops);
- short vehicle life-cycle and high annual depreciation;
- high operational costs due to onboard safety drivers.

In a third step, the externalities methodology, boundaries, limitations and assumptions for the estimations of the marginal costs are explained. The impacts that are considered for monetisation are also detailed. Then, the marginal costs for the modes of automated minibuses are defined. To further support the model, the economic deliverable included a fleet calculator that estimated the fleet size needed to replace different modes of transportation with the on-demand automated minibuses. Furthermore, in the second iteration of the economic deliverable an example of externalities calculations applied to a scenario was included. The case study in Geneva was about replacing the future increase in transport demand for individual vehicles with automated minibuses. The calculations showed potential high avoidance costs of around 6000 million euros with the lion's share going to the congestion costs (Antonialli et al. 2021).

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3 Sustainability assessment of the AVENUE demonstrator pilot sites

This section applies the set of indicators (Table 1) presented on D8.11 First Iteration Sustainability Assessment and the final version of the article of Nemoto et al. (2021). Further, it presents a preliminary radar for sustainability assessment of the automated minibuses based on data from the demonstrator pilot sites of Groupama (Lyon), Contern (Luxembourg), Pfaffenthal (Luxembourg), Nordhavn (Copenhagen) and Ormoya (Oslo). The assessment comprehends the mobility multi-dimensions: social, environmental, economic, governance and system performance. Based on data availability, 13 out of 20 indicators are assessed in this preliminary version.

Table 1. Set of indicators for sustainable mobility assessment of shared automated electric vehicles from Nemoto et al. (2021).

		Multidimensions				
Indicators	**Unit and methods of measurement**	**S**	**En**	**Ec**	**G**	**SP**
Accessibility	• Percentage of the city (area) coverage by the AM service • Percentage of the population that has convenient access (within 0.5 km) to the AM service					
	• AM digitally accessible (e.g. via apps)					
Accessibility for people with reduced mobility	• External environment facilities e.g., stops adaption for impaired/disabled people; tactile surfaces information • Internal environment facilities e.g., audible warning equipment for visually impaired people; facilities for wheelchair users					
	• Usability of the SAEV by people with reduced mobility (PRM) • Rating of users with reduced mobility concerning the AM experience					
Safety	• Risk factor and number of accidents related to the AM (mild injuries, serious injuries, fatalities) considering internal risk (related to passengers) and external risk (related to other road users, pedestrians and cyclists)					
Security	• Number of criminal occurrences; nr/year					
	• Number of cybersecurity threats or attacks; nr/year					
Passenger's affordability	• The price of the ride on the AM					
User acceptance	• User's perception about the readiness of the technology • User's willingness to pay • Safety feeling • Security feeling					
User satisfaction	• User rating concerning AM experience (comfort, speed, punctuality, information, frequency, connection to other means of transport)					
Energy efficiency	• Energy consumed for passenger per km (kWh/pkm)					
Renewable energy	• Use phase: Energy source and percentage of renewable energy sources (%)					
Air pollution	• AM emissions of air pollutants: PM levels (ug/m3), NOx, CO emissions					
Climate change	• AM GHG emissions: CO_2, N_2O, CH_4					
Noise pollution	• AM traffic noise (dB)					

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Investments on mobility	• Public and private annual average investment on transport concerning automated vehicles (Euro/year), e.g. infrastructure, operational expenditures (cost of personnel, software system, etc.), investments in the vehicle R&D					
Economic incentives for SAEV and sustainable mobility	• Incentives and subsidies for automated and sustainable mobility, e.g., shared, electric, automated, zero-emission, vehicles (Euro)					
Economic profitability	• TCO (Total Cost of Ownership), TCM (Total Cost of Mobility), Cost/km/passenger, revenues (ticketing from passengers, subsides from authorities and companies), and payback period					
External costs related to the AS	• AM impacts on congestion avoidance, accidents reduction, noise reduction, air pollution (PM, NOx) reduction, QALY (quality-adjusted life years) reduction, land/parking reduction, vehicle savings					
Institutional development and innovation	• Existence of policies and regulations concerning automated vehicles • Regulations for open data and/or APIs for transport					
Technical performance and reliability	• AM performance: . travel time: speed, frequency of departure or response speed for on-demand, travel-matching, punctuality. . on-demand availability . percentage of operational service . performance on different seasons/weather . vehicle occupancy (average passenger per km travelled) . the average lifetime of the vehicle . number of disengagements in the urban environment, number of km driven autonomously					
System integration and efficiency	• AMV integration with mobility platform of the operator (planning, reservation, booking, billing, digital ticketing) • System and data interoperability and the existence of open data for the AM (access, static and/or dynamic real-time data, diffusion format, data quality, and open APIs for transport) • Intermodality: AM integration with other public or private means of transport or with a multi-modal platform for one intermodal trip (planning, reservation, booking, billing, digital ticketing)					
Changes in total kilometres travelled in the transportation system	• Changes in per capita vehicle travelled induced by automated vehicles • Transportation demand management measures introduced congestion pricing, biking lanes, zoning measures, land-use policies					

Acronyms	Nr/year: number per year	R&D: Research and Development
AM: automated minibus	NOx: nitrogen oxides	SAEV: shared automated electric vehicle
APIs: Application Programming Interfaces	Pkm: per kilometre	S: social
dB: decibel	PM: particular matter	SP: system performance
Ec: economic	PRM: people with reduced mobility	TCM: Total Cost of Mobility
En: environment	QALY: quality-adjusted life years	TCO: Total Cost of Ownership
G: governance		

3.1 Description of the indicators and methods

The following guidelines provided the basis to develop and adapt the methods for the indicators in this deliverable:

- ‘Sustainable Urban Mobility Indicators – SUMI’ by the (European Commission 2020b)
- ‘Methodology and indicator calculation method for sustainable urban mobility’ by the (World Business Council for Sustainable Development 2015). In this document, based on the indicators and methods, a mobility radar is built to represent the assessment of the cities mobility system.

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Hereinafter, for each indicator we present a definition, parameter, description of the methodology, scale (min and max), and examples of the indicator value within a range from 1 to 5 – with 1 for the worst performance and 5 for the best performance.

The normalisation step adjusts all indicators into a common scale (Saisana et al. 2019). The method of normalisation chosen is the re-scaling (EU Science Hub 2016) - defining max and min scale – and in some cases, categorical scales for more conceptual assessment (EU Science Hub 2016) – which defines categories - for instance, system integration and MaaS level.

The disaggregated indicators reveal the strengths and weaknesses of each mobility indicator (World Business Council for Sustainable Development 2015). As graph representation, the radar (also known as spider chart) enables easy communication and visualisation of the results and comparison among case studies.

3.1.1 Social acceptance

Definition: potential users' opinions, positionings and attitudes towards the automated minibuses.
Parameter: average rating reported concerning the i) willingness to use automated minibus; ii) perception about the readiness of the technology; iii) willingness to pay; iv) safety and security feeling.
Methodology: AVENUE representative survey and users' survey. The questions presented a scale from 1 to 5, with 1 corresponding to very low acceptance and 5 to very high acceptance. For more details, refer to appendix A and D8.7 Second Iteration Social Impact Assessment.

Scale:

1 = very low acceptance

5 = very high acceptance

Calculation:

Social acceptance				
Indicator value	3,59			
Willingness to use the automated minibus			1	5
Parameter value:	3,94		min scale	max scale
Indicator value	3,94		1	5
Perception about the readiness of the technology			1	5
Parameter value:	2,69		min scale	max scale
Indicator value	2,69		1	5
Willingness to pay			1	5
Parameter value:	2,79		min scale	max scale
Indicator value	2,79		1	5
Safety feeling			1	5
Parameter value:	4,09		min scale	max scale
Indicator value	4,09		1	5
Security feeling			1	5
Parameter value:	4,43		min scale	max scale
Indicator value	4,43		1	5

Obs: Example of Nordhavn (Copenhagen)

Sources: Korbee et al. (2021), D8.7 Second Iteration Social Impact Assessment.

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3.1.2 User satisfaction

Definition: users' experience, satisfaction and perceptions on-board the automated minibuses.

Parameter: average rating satisfaction reported concerning the automated minibuses speed, comfort, punctuality, information, frequency of service, connection to other means of transport, and satisfaction with the last ride.

Methodology: AVENUE users' survey. The questions presented a scale from 1 to 5, with 1 for very poorly rated and 5 for very good rate. For more details, refer to appendix B and D8.7 Second Iteration Social Impact Assessment.

Scale:

1 = very poorly rated/very dissatisfied

5 = very good rated/very satisfied

Calculation:

User satisfaction

User rating concerning the ride experience			1	5
Parameter value:	3,96		min scale	max scale
Indicator value	3,96		1	5

Obs: Example of Nordhavn (Copenhagen)

Sources: Korbee et al. (2021), D8.7 Second Iteration Social Impact Assessment.

3.1.3 Safety

Definition: risk factor calculated based on the 'fatalities of active modes users in traffic accidents in the city in relation to their exposure to traffic' (European Commission 2020b). In this context, it accounts for internal or external fatalities directly related to the automated minibus in relation to traffic exposure.

Parameter: Fatalities per billion passenger-km

Methodology: Risk factor calculation adapted from SUMI methodology (European Commission 2020b):

RF = K/Exp

RF = risk factor for the automated minibus

K = number of fatalities

Exp = exposure, defined as passenger km (in billion).

Scale: adaptation scale from SUMI (European Commission 2020b).

1= 2,5 fatalities per billion passenger-km

5= 0 fatalities per billion passenger-km

Calculation:

Safety

Internal and external risk factor			1	5
Parameter value:	0,00		min scale	max scale
Indicator value	5,00		2,5	0

Obs: Example of Ormoya (Oslo)

Source: SUMI (European Commission 2020b), European Union Agency for Railways (2020).

3.1.4 Passenger affordability

Definition: Transportation affordability refers to 'household's ability to purchase basic mobility within its limited financial budget' (Litman 2021). Therefore, in this study, the price of the ride on the automated minibus is assessed.

Parameter: costs (Euro) passenger-km for passengers

Methodology:

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range of price to compare the price of the ride in the automated minibuses with others modes of transport. Currently, the ride in the automated minibuses is free of charge in all sites.
Scale: the scale range considers the costs (Euro)/ passenger-km for bus, minibus, car and van according to the study from (Bösch et al. 2018) and free of charge modes of transport.
1= 0 euro pkm (free of charge)
5= 1,25 euros pkm (approximation from the price of a driver-operated taxi)
Calculation:

Passengers' affordability		1	5
Parameter value:	0,00	min scale	max scale
Indicator value	5,00	1,25	0

Obs: Example of Pfaffenthal (Luxembourg)

Sources: Bösch et al. (2018), Antonialli, Mira-Bonnardel and Bulteau (2021) within the D8.4 Second Iteration Economic impact (Antonialli et al. 2021).

3.1.5 Climate Change

Definition: greenhouse gases emitted by the EASB shuttle per passenger-km
Parameter: gCO_2 eq/pkm
pkm = passenger kilometres, a metric of transport activity: when a single passenger travels a single kilometre, the result is 1 pkm of travel.
gCO_2eq = grammes of CO_2 equivalent.
Methodology: the LCA study (section 2) provided the GHG emissions (gCO_2 eq/pkm) for the EASB.
The scale was developed based on values reported on the average GHG emissions of different modes of transport on a well-to-wheel basis by the International Energy Agency 2020) and the LCA study from the AVENUE project (Huber et al. 2019). Those studies comprehend the GHG emissions (gCO_2eq/pkm) for two/three-wheelers, buses and minibuses, small/medium and large vehicles as individual transportation or public transport. Following these references, emissions levels equal to or higher than 300 CO_2eq/pkm are defined as maximum scale.
Scale:
1 = ≥ 300 gCO_2eq/pkm
5 = 0 gCO_2eq/pkm
Calculation:

Climate Change		1	5	
Parameter value:	197,0	min scale	max scale	
Indicator value	1,72	300	0	gCO_2/pkm

Obs: Example of Contern (Luxembourg)

Sources: Huber et al. (2019), International Energy Agency (2020)

3.1.6 Renewable energy

Definition: use of renewable energy for the mode of transport.
Parameter: percentage of renewable energy in the use phase of the mode of transport.
Methodology: the measurement takes into account the use of renewable fuels according to the energy sources for the mode of transport. The automated shuttle is a battery electric vehicle (BEV). Therefore, the electricity mix of each country may influence the percentage of renewable energy used in the vehicle use phase.

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For the calculation, it was considered the share of energy from renewable sources in gross electricity consumption 2018 (%) according to the countries of the pilot tests (The Federal Council 2019; Eurostat 2020) (refer to appendix D).

Scale:

1 = 0%

5 = 100%

Calculation:

Renewable energy			1	5	
Parameter value:	21,2		min scale	max scale	
Indicator value	1,06		0	100	% renewable energy

Obs: Example of Groupama Stadium (Lyon)

Sources: Eurostat (2020), The Federal Council (2019), European Environment Agency (2016), Litman (2019).

3.1.7 Noise pollution

Definition: noise emission by the mode of transport.

Parameter: vehicle noise in Decibels (dB) at 15km/h.

Methodology: Considering the uncertainty and variations among noise emissions studies, we describe here in more detail the noise measurement for this indicator.

> *"The noise from vehicles comes mainly from two different sources, the propulsion and the contact between the tyres and the road. The tyre/road noise increases more with increasing speed than the propulsion noise, and therefore the tyre/road noise dominates the propulsion noise at high speeds." (Marbjerg 2013).*

Hence, the difference in noise emissions between BEVs and ICEVs strongly depends on the vehicle speed (European Environment Agency 2018).

A study from Jochem et al. (2016) pointed that taking into account the background noise and traffic density, EV does not differ from ICEV in the usual traffic, except for urban traffic during the night at low-speed areas. Moreover, the extent of noise reduction will also depend strongly on the proportion of BEVs in the vehicle fleet (EEA, 2018).

To simplify the measurement for noise emission, the study from Marbjerg (2013), 'Noise from electric vehicles - A literature survey', provided the basis for comparing the noise emissions from different modes of transport (ICE, hybrid and electric vehicles) at different speed levels.

Considering that the automated shuttle drives at an average speed of 11-15km/h in areas with a speed limit of 30km/h, the noise difference reported for different vehicles were considered at 30km/h (Dudenhöffer, Hause 2012; Lelong and Michelet 2001; Marbjerg 2013; Cai 2012). The noise emission for the automated shuttle was considered similar for a BEV, as 58 decibels in constant speed at 30km/h.

Scale:

1 ≥ 75dB

5 = 0 dB

Calculation:

Noise pollution			1	5	
Parameter value:	50		min scale	max scale	
Indicator value	2,33		75	0	Decibels

Sources: European Environment Agency (2018), Marbjerg (2013), Jochem et al. (2016), Cai (2012), Dudenhöffer, Hause (2012), Lelong and Michelet (2001).

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3.1.8 Air pollution

Definition: air-polluting emissions by the modes of transport in the use phase.

Parameter: air pollutant emissions, particular matter, $PM_{2,5}$ (g/km), and nitrogen oxides, NO_x (g/km), from exhaust and non-exhaust.

Methodology:

Particulate matter (PM) and nitrogen oxides (NO_x) are the main transport air pollutant emissions along with carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs) and sulphur oxides (SOx). The emissions from road transport are mainly exhaust emissions arising from fuel combustion, and non-exhaust releases contribute to NMVOCs (from fuel evaporation) and

primary PM due to tyre- and brake-wear and road abrasion (European Environment Agency 2019). Further, transport is responsible for more than half of all NOx emissions (ibid).

The automated shuttle is a BEV, and during the use phase, BEVs have zero exhaust emissions, e.g. NOx and PM (European Environment Agency 2018). However, BEVs emit PM locally from road, tyre and brake wear, like other motor vehicles (European Environment Agency 2018). And it is important to mention that air pollutant emissions from BEVs occur for the electricity generation to charge BEV batteries. Nonetheless, the emissions from power stations tend to occur in less densely populated areas, provoking less human exposure to air pollution than in urban areas (ibid). At the same time, the local emissions from combustion engine vehicles in cities provokes greater human exposure and potential health harm.

Considering this factor, we limited the impact measurement for air pollutant emissions to the use phase and local area. And we considered the assumption that the automated shuttle present similar air pollutant emissions as an electric car.

Values from $PM_{2,5}$ (g/km) from exhaust and non-exhaust and NO_x (g/km) by mode of transport are provided by the excel tool 'Air pollutant emissions indicator' on Sustainable Urban Mobility Indicators (SUMI) (European Commission 2020b). (Appendix B)

Scale:

$PM_{2,5}$

1 ≥ 0,005 $PM_{2,5}$ g/km

5 = 0 $PM_{2,5}$ g/km

NO_x

1 ≥ 0,08 NO_x g/km

5 = 0 NO_x g/km

$PM_{2,5}$ Non exhaust

1 ≥ 0,0474 $PM_{2,5}$ g/km

5 = 0 $PM_{2,5}$ g/km

The Euro 6 standards for light-duty (cars, vans) were considered to establish the maximum values in the scale (European Commission 2020a). The emission limits are presented in Table 19.

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Table 2: The light-duty Euro 5 and Euro 6 vehicle emission standards (g/km)

Pollutant	Euro 5 Light-Duty		Euro 6 Light-Duty	
	Gasoline	Diesel	Gasoline	Diesel
CO	1.0	0.5	1.0	0.5
HC	0.1[a]		0.1[e]	
$HC+NO_X$		0.23		0.17
NO_X	0.06	0.18	0.06	0.08
PM	0.005[c]	0.005	0.005[c]	0.005
PN (#/km)		6.0×10^{11}	6.0×10^{11} [d]	6.0×10^{11}

[a] and 0.068 g/km for NMHC; [c] applicable only to DI engines, 0.0045 g/km using the PMP measurement procedure; [d] applicable only to DI engines, 6 x 1012 #/km within the first three years of Euro 6 effective dates.

Source: Williams and Minjares (2016)

Calculation:

Air pollution

Indicator value	4,60

PM 2,5

			1	5	
Parameter value:	0,00		min scale	max scale	
Indicator value	5,00		0,005	0	PM 2,5 g/km

NOx

			1	5	
Parameter value:	0,00		min scale	max scale	
Indicator value	5,00		0,08	0	NOx g/km

Non exhaust

			1	5	
Parameter value:	0,01		min scale	max scale	
Indicator value	3,79		0,0474	0	Non exhaust PM2,5 g/km

Sources: European Environment Agency (2018), Jochem et al. (2016), (European Commission 2020a), European Commission (2020b), European Environment Agency (2019).

3.1.9 Energy Efficiency

Definition: energy consumption (kWh) by the EASB shuttle per passenger-km

Parameter: kWh/pkm

kWh = kilowatt-hour

pkm = passenger kilometres, a metric of transport activity: when a single passenger travels a single kilometre, the result is 1 pkm of travel.

Methodology: the LCA study (section 2) provided the energy consumption of 0,52kWh/km for the EASB. The scale was developed based on values the methodology for 'energy efficiency' indicator from the World Business Council for Sustainable Development (WBCSD, 2015), which also considered the energy use by urban transport per passenger-km.

Scale:

1 = ≥ 0,97 kWh/pkm

5 = 0,14 kWh/pkm

Calculation:

Energy efficiency

Parameter value:	0,18		min scale	max scale	
Indicator value	4,74		0,97	0,14	KWh/pkm

Obs: Example of Pfaffenthal (Luxembourg)

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Sources: Huber et al. (2019), WBCSD (2015).

3.1.10 Economic profitability

Definition: the ability of the transport operator to generate profits (more revenues than costs) through its operations.
Parameter: costs (Euro)/passenger-km for operators
Methodology: the Total cost of ownership tool (EASI-AV©) for the automated shuttles was developed by Antonialli, Mira-Bonnardel and Bulteau (2021) within the D8.4 Second Iteration Economic impact (Antonialli et al. 2021). The study calculated the TCO of the four demonstrator cities (refer to appendix C).
Scale: the scale range considers the costs (Euro)/ passenger-km for bus, minibus, car and van according to the study from (Bösch et al. 2018). In addition, the costs estimations for fully autonomous vehicles in a ride-sharing scheme for Germany (Friedrich and Hartl 2016) and Netherlands (Hazan et al. 2016).
1= 0,15 euro pkm
5= 1,25 euros pkm (approximation from the costs of a driver operated taxi)
Calculation:

Economic profitability			1	5
Parameter value:	0,74		min scale	max scale
Indicator value	2,32		1,25	0,15

Obs: Example of Groupama (Lyon)

Sources: Bösch et al. (2018), Antonialli, Mira-Bonnardel and Bulteau (2021) within the D8.4 Second Iteration Economic impact (Antonialli et al. 2021), Friedrich and Hartl (2016), Hazan et al. (2016).

3.1.11 Technical performance of the vehicle

Definition: technological maturity and performance of the automated minibus assessed by average speed, frequency or response speed for on-demand, average occupancy (very important in terms of environmental performance and efficiency), and kilometres driven autonomously.
Parameter: i) average speed in km/h; ii) frequency or response speed in minutes of waiting time, iii) average occupancy as the average number of passengers on board at any given time and any place within a trip and iv) the percentage of kilometres driven autonomously.
Methodology: average of performance for the four variables described below.
Scale: the following scales for assessment were established:

i) Speed

1= 6km/h
5= 25km/h (25km/h is the current maximum operating speed of the minibus. In addition, they are running in areas of about 30km/h)

ii) Frequency

1= 5 minutes
5= 40 minutes (It takes into account that in some areas the minibus complement bus services running every 30 minutes, also in order to be competitive with on-demand services a minimum of 5 minutes is settled in comparison with taxis services, with an average of waiting time of 4:32minutes (Bischoff et al.).

iii) Average occupancy

1= 1
5≥ 6 passengers

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iv) Km driven autonomously

1= 60%

5= 100%

Calculation:

Technical performance	
Parameter value:	3,1
Indicator value	3,14

Speed			1	5	
Parameter value:	17		min scale	max scale	
Indicator value	2,89		6	25	km/h

Frequency or response speed for on-demand			1	5	
Parameter value:	15		min scale	max scale	
Indicator value	3,57		40	5	minutes

Average occupancy rate			1	5	
Parameter value:	2,84		min scale	max scale	
Indicator value	1,84		1	6	passengers on board

Km driven autonomously			1	5	
Parameter value:	94		min scale	max scale	
Indicator value	4,25		60	100	% km drive autonomously

Obs: Example of Pfaffenthal (Luxembourg)

3.1.12 System integration

Definition: Integration of various modes of transport offered by different mobility providers in one platform that allows the planning, reservation, booking, billing, and ticketing.

Parameter: five levels of MaaS integration suggested by (Sochor et al. 2018).

Methodology: categorical scale based on the MaaS levels conceptualised by Sochor et al. (2018)

Scale: 1) No integration - single, separate services

2) Integration of information - multi-modal travel planner, price info

3) Integration of booking & payment - single trip, find, book and pay

4) Integration of the service offer - bundling/subscription, contracts, etc.

5) Integration of societal goals - policies, incentives, etc.

Calculation:

System integration				
Mobility Integration			1	5
Parameter value:	1		min scale	max scale
Indicator value	1,00		1	5

Obs: Example of Contern (Luxembourg)

Source: Sochor et al. (2018)

3.1.13 Potential induced demand

Definition: potential increase of vehicle kilometres travelled in the transportation system due to the offer of new mobility services by the automated minibus.

Parameter: percentage of motorised modes of transport – car and buses – that the automated minibuses are replacing based on the reference modal share.

Methodology: Gorham (2009) describes four characteristics of induced travel:

i) Induced travel at the metropolitan level is concerned with travel as a whole, not trip-making per se;

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ii) The concept of induced travel applies to the entire transportation sector, not just to one mode;

iii) Induced travel is not the only source of growth in the demand for travel.
Besides induced travel due to improvements in transportation conditions (e.g. better infrastructure, roads, better technologies), it can also occur due to "natural demand growth" due to changes in population, employment, income, socio-demographics for instance;

iv) Induced travel can only be understood with reference to a hypothetical "base" case or counterfactual.

The measurement of induced demand triggered by the integration of the automated minibus is complex, and for this study, it presents significant limitations due to the small scale of the tests, therefore, not representing meaningful mobility impacts. In addition, there is not available accurate data on the mobility behaviour on the local scale of the pilot sites. Therefore, the assessment is simplified to the potential risks of induced vehicle travelled caused by the automated minibuses according to the means of mobility that they have replaced. The data is provided by the AVENUE users' survey.

Scale:

1= 0% replacement of individual cars or buses

5= 100% replacement of individual cars or buses

Calculation:

Reduction of risk of induced demand			1	5
Parameter value:	27		min scale	max scale
Indicator value	1,36		0	100

Obs: Example of Nordhavn (Copenhagen)

3.2 Results

The indicators were applied for the sustainability assessment of five different demonstrator sites. The description of the sites and respective mobility radar are presented hereinafter. The indicators present a value from 1 to 5 – with 1 for the worst performance and 5 for the best performance – therefore, the outside part of the radars represent the optimal results.

It is worth noting that the data availability varies from site to site. For instance, the 'user satisfaction' and 'risk of induced demand' are so far available just for Nordhavn. Moreover, data for the assessment were not available for Meyrin and Belle Idée, the demonstrator sites deployed in Geneva. As next steps on the sustainability assessment, more data will be collected from the sites and a comparison will be presented based on the final results. Table 3 summarises the main information on the pilot sites.

Table 3. Description of the demonstrator sites

City	Pilot	Characteristics of route	Type of passenger	Deployment
Lyon	Groupama Stadium	Fixed route with stops 1.3 km. Will become an on-demand, door-to-station service	regular workers, people with reduced mobility (medical centre nearby)	November 2019 - April 2022
Copenhagen	Nordhavn	Fixed route with stops, 1,2km, will become an on-demand, door-to-door service	Residents of the area, tourists	September 2020– April 2022
Oslo	Ormøya	Fixed route with stops, 1,6 km,	Residents of the area	December 2019 – April 2022

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Luxembourg	Contern	Fixed route with stops, on-demand. 2.2 km	Employees working at Campus Contern	September 2018 - April 2022
	Pfaffenthal	Fixed route with stops, on-demand 1.2 km	Workers, tourists, residents, and visitors of Luxembourg city	September 2018 - April 2022

3.2.1 Groupama Stadium (Lyon)

Groupama Stadium, also known as Parc Olympique Lyonnais is a football stadium. The area is a high traffic district, and it attracts visitors going to the football games, people working in offices, medical centre, leisure centre, hotels, and restaurants.

To access the Groupama Stadium by public transport, the area is served by the Tramway 3 line and a bus every 30 minutes to connect the area. The automated minibuses route is parallel to the bus line, and the service is complementary to the bus (Zuttre 2019). The automated minibuses route comprises crossroads and roundabout with the vehicle to infrastructure (V2I) intersections (Zuttre 2019). For the near future, it is envisaged on-demand and door-to-door services in Parc Olympique Lyonnais.

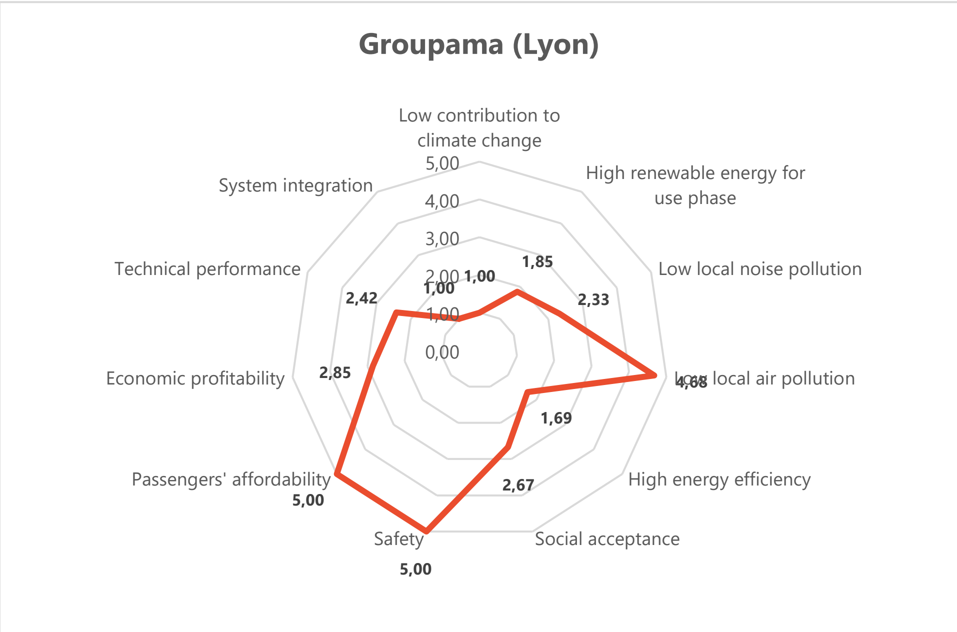

Figure 4. Mobility Radar for Groupama Stadium

In general, the environmental indicators such as low contribution to climate change and energy efficiency score low mainly due to the low passenger occupancy. This occurs in Groupama site as well as in other pilot sites. The user acceptance in Lyon scores medium, reflecting the willingness to use the automated minibuses (2,76) and the willingness to pay (2,59) for most of the respondents is equivalent to the public transport fee for the automated minibuses services. The technical performance is affected by the low speed (10km/h) and low occupancy. Other aspects are discussed in the next section, 3.3.

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3.2.2 Pfaffenthal (Luxembourg)

Pfaffenthal is a residential area located in a valley between the historical centre of Luxembourg City and Kirchberg, the business district of Luxembourg City. During the peak hours, work commuters move through Pfaffenthal, and along the day, local residents and a vast number of tourists (Reisch 2019). The automated minibuses route in Pfaffenthal connects the public elevator, which provides access to the city centre, a multi-modal station and the residential area (Reisch 2019). Figure 5 illustrates the mobility radar for Pfaffenthal.

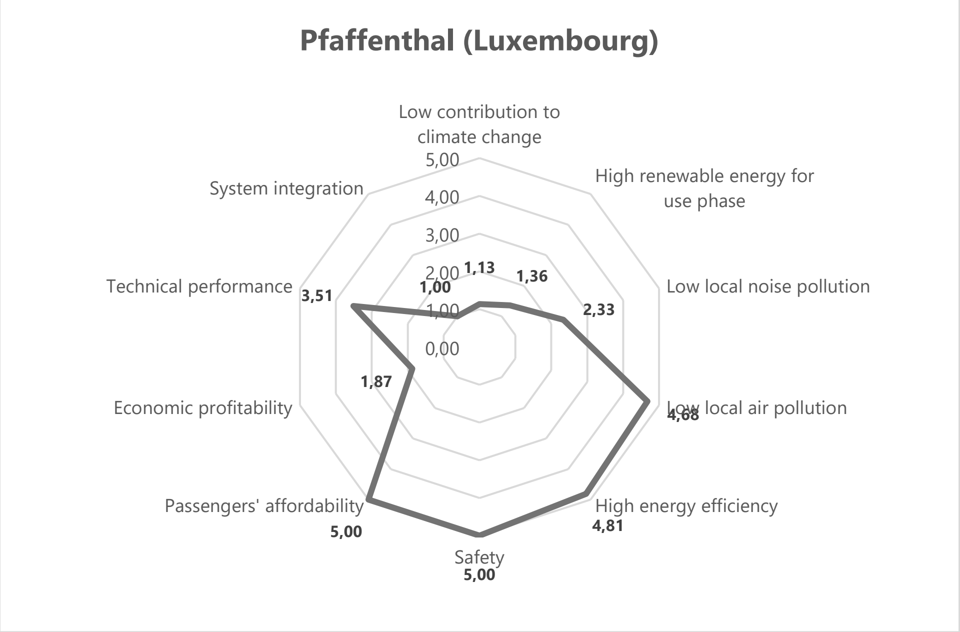

Figure 5. Mobility Radar for Pfaffenthal

Among all the sites, Pfaffenthal scores the highest in technical performance, with 17km/h speed, 94% of km driven autonomously, and average occupancy of 3 passengers. The higher vehicle occupancy also reflects a better energy efficiency (in terms of kWh/passenger-kilometre). Additional aspects are commented on in section 3.3.

3.2.3 Contern (Luxembourg)

Contern is an industrial zone with different companies located around 10 km east of Luxembourg city. The traffic in Contern consists of industrial vehicles, as trucks and individual cars (Reisch 2019). A railway station and a bus are located on the border of the industrial zone of Contern; however, the area is not served by public transport. Thus, the companies employees use mainly private cars to commute to work and to move inside this area (Reisch 2019). The route of the automated minibuses connects the public transport to the industrial zone. Figure 6 shows the mobility radar for Contern.

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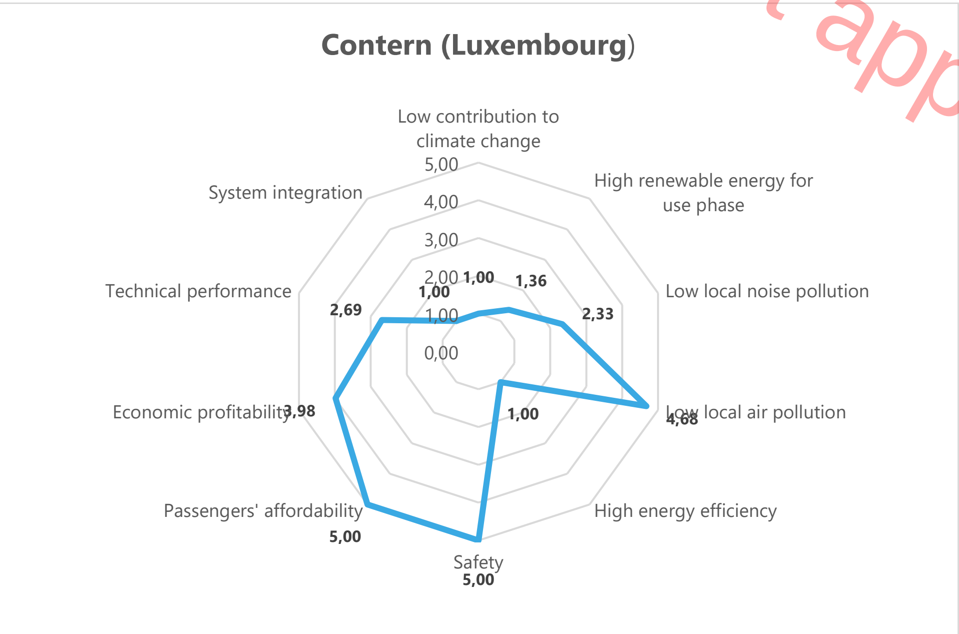

Figure 6. Mobility Radar for Contern

3.2.4 Nordhavn (Copenhagen)

Nordhavn is an active industrial port, which is expected to be Copenhagen's new international waterfront district, with residential and commercial buildings (Guldmann et al. 2019). The area hosts eco-friendly initiatives as the use of renewable energy, recycling of resources (Guldmann et al. 2019).

Nordhavn area is served by a tram station about 1km away, and bus stops located near the train station; however, there are no buses or trains running directly in the area, which creates an opportunity for automated minibuses services to connect the area. Figure 7 presents the mobility radar for Nordhavn.

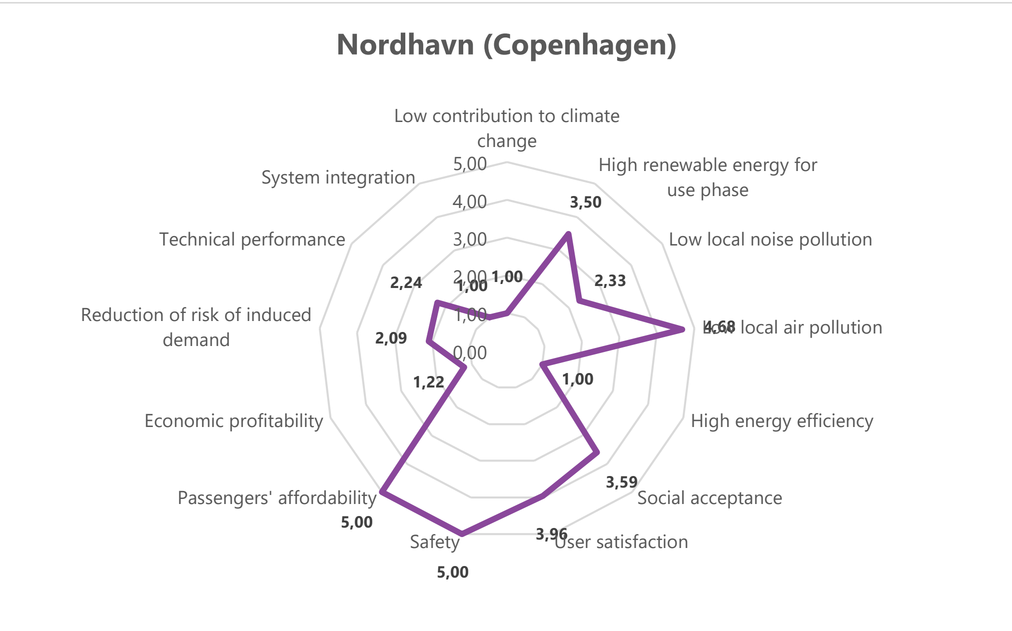

Figure 7. Mobility Radar for Nordhavn

Interesting points from Nordhavn site concern the user acceptance; it scores good, with a high willingness to use the automated minibuses (3,94) and high safety and security feeling (4,09 and 4,43). The user

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satisfaction is also high (3,96) regarding the speed, comfort, punctuality, information and general satisfaction with the ride. An important point assessed concern the 'risk of induced demand', the user surveys pointed that currently, the automated minibuses have been replacing high percentages of walking and cycling (17% and 45%, respectively). In parts, this can be explained due to the vehicles' low speed. However, in the future, the goal is the replacement of other motorised modes of transport and to foster mobility intermodality by deploying automated minibuses. In addition, the technical performance of the vehicle is affected by the low vehicle speed (8km/h).

3.2.5 Ormøya (Norway)

Ormøya is an island situated in the south of Oslo city. It is connected by a bridge to the mainland, and another bridge connects Ormøya to a second island called Malmøya.
The automated minibuses services are offered for the residents of the area in order to increase the frequency of public transport, aiming to reduce the need for the use of private cars (Zinckernagel 2021). The service complements the buses schedule, with departures every hour. The automated minibuses service provides a high frequency of first and last mile solution for the residents of Ormøya and Malmøya, which connected them to the express service on Mosseveien/E18 (Zinckernagel 2021). Figure 8 shows the mobility radar for Ormoya.

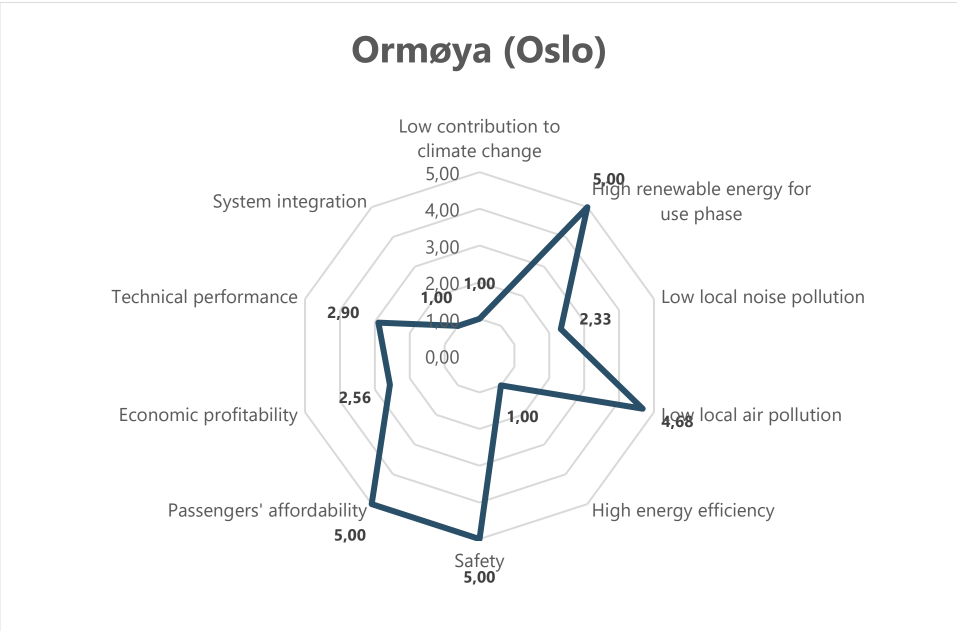

Figure 8. Mobility Radar for Ormoya

3.3 Discussion and concluding remarks

The preliminary results from the sustainability assessment reveal strong and weak points of the deployment of the automated minibuses. Some common results among the sites pointed that:

- the automated minibuses score poorly on 'energy efficiency' and 'low contribution to climate change' due to the low vehicle occupancy. With the exception of Pfaffenthal (Luxembourg), all sites presented very low occupancy. This result can be an indication of low demand for the offered mobility services. However, we should be cautious in this conclusion due to the unknown impacts of the Covid-19 restrictions. In addition, the energy efficiency could also be affected negatively in

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case the automated minibuses were equipped with more hardwares and technical features, such as sensors, cameras, Lidars and communications.

- as electric vehicles, automated minibuses seem to be a good alternative to tackle 'local air pollution'. However, they are not a significant solution to tackle 'local noise pollution', as their noise level does not differ that much from other motorised modes of transport from 30km/h speed. It considers that the background noise and traffic density, EV does not differ from ICEV in the usual traffic, except for urban traffic during the night at low-speed areas (Jochem et al., 2016)
- the safety indicator for automated minibuses scores high; however, be cautious, as the safety indicator used in this study is simplified by accounting for the number of fatalities per billion passenger-km per mode of transport. So, since no severe injuries, neither fatalities occurred internally or externally the automated minibuses, the safety factor scores high. In addition, metrics and methods for assessing the safety performance of the automated driving system (ADS) are being developed by the Society of Automotive Engineers (SAE). For instance, safety outcomes can be measured by the crash severity and frequency, or by predictive metrics, as the safety envelope maintenance, vehicle motion control (SAE 2021). According to data availability, these metrics could be embedded in our assessment.
- as temporary pilot trials, the automated minibuses present low system integration. Nonetheless, they present a high potential in the near future to have information, booking and payment integration within the public transport services, considering that in most of the cases, they are deployed already by public transport operators.
- Concerning the technical performance elements (speed, frequency, occupancy rate, and km driven autonomously): all sites struggle with low speed and low occupancy rates. The percentage of fully automated driven kilometres is 80 to 94%. The manual interventions that took place were mainly caused by wrongly parking cars and trucks.

The main points that differ among the sites:

- the use of renewable energy for the use phase varies significantly according to the electricity mix of each region or country. In this case, Ormoya in Norway has the best score and Contern and Pfaffenthal in Luxembourg the lowest.
- passenger's affordability
- overall, the economic profitability is still low due to the elevated costs with feasibility studies and legal authorisations; infrastructure works; high annual depreciation and salaries for on-board safety drivers impact as detailed on the second iteration economic Impact assessment (Antonialli et al. 2021)

Concerning the indicators on user acceptance and user satisfaction, data were available for Groupama and Nordhavn sites. The results point that the willingness to use and pay for the automated minibus service is higher in Nordhavn site (Copenhagen) than in Groupama site (Lyon).

The indicator on 'reduction of risk of induced demand' scored low in Nordhavn; this is explained by the users' survey, which shows that the automated minibuses have been replacing walking and cycling (17% and 45% respectively). In parts, this can be explained due to the vehicles' low speed.

All in all, the indicators reflect an incipient phase of deployment and development of the technology. In the short-term, key factors for improvement are:

i) the minibuses' occupancy, a key factor to foster environmentally-friendly mobility. The automated minibuses should be deployed to cover real mobility gaps and to provide rides with great potential to replace private cars. These factors are crucial to guarantee higher occupancy and reduction of the risks of induced demand and increase in vehicle kilometres travelled.

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ii) better mobility services integration, as the integration of information, booking & payment

iii) offer of permanent lines/services, on-demand services and higher speed as a factor to improve flexibility and reduce travel time

iv) monitoring and planning the deployment in order to replace more cars and buses trips.

In the medium and long term, the economic profitability to deploy the automated minibuses should become more attractive by the development of a legal framework and lower costs with feasibilities studies, authorisations, and exemption of safety drivers.

For the next steps, more indicators will be developed, and more data will be collected in AVENUE test sites. In this regard, the indicators are a tool to measure and monitor the progress and achievement of sustainable mobility planning and goals. To this end, Figure 9 presents the AVENUE pilot sites current average performance, and it set goals for the near future (next 3 to 5 years

As next steps, the mobility radar will also include the scenarios assessment described in section 2.2.3, e.g. the integration of AM in ITS as the best case and robotaxi as worst case scenarios. It may also include a validation of the goals of the cities (see figure 9) in comparison to the worst and best case is aimed.

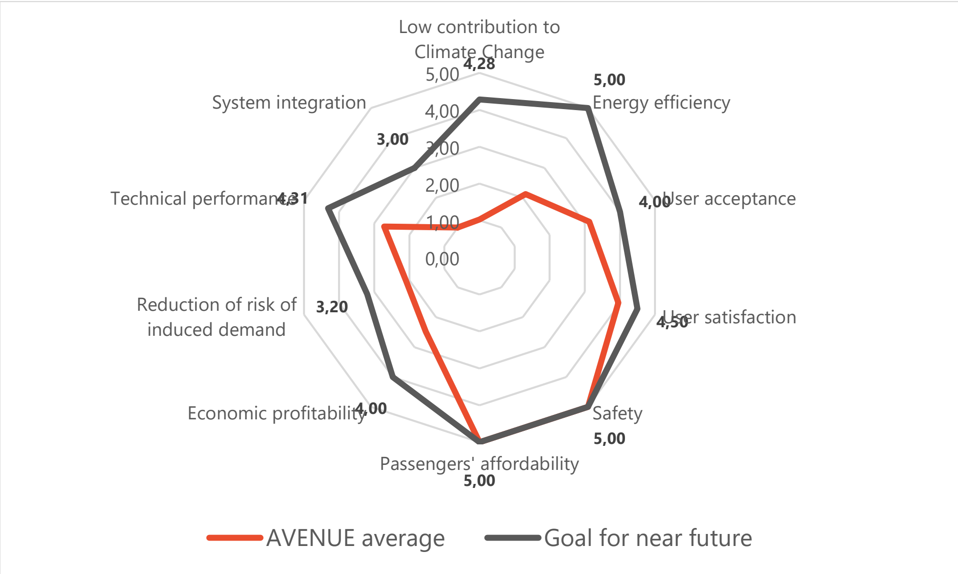

Figure 9. AVENUE pilot sites performance and goals for the near future

Concerning the SUMP concept, it is worth noting that automated vehicles and minibuses per se will not be sustainable, but rather their mode of deployment is very important, and factors such as shared mobility, ride-matching capacity and efficiency, system integration and means of transport it will replace proper policies and regulations. The automated minibuses should be integrated into urban public transport or within MaaS perspective and fundamentally aligned with the city's goals, planning and strategies for sustainable mobility. Also significant is to keep an integrated vision on the mobility system. And as highlighted by SUMP approach, to develop all modes of transport in an integrated manner. Thus, the automated minibuses are a piece within the mobility ecosystem that could support intermodality, MaaS, mobility hubs and the use of soft modes of transport.

Concerning SUMP principles, the deployment of this new mode of transport and new mobility technologies require more than ever long-term vision and planning, development of all transport modes in an integrated manner, cooperation across institutions, stakeholders and citizens' participation, performance assessment and monitoring towards established sustainability goals.

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Therefore, SUMP principles and four steps guidelines are a valuable tool for planning and implementing automated minibuses aiming at people's mobility needs and better quality of life. Afterwards, chapter 5 presents the research outlook for the final sustainability iteration.

3.4 Limitations

The application of the set of indicators for sustainability assessment of the automated minibuses and sites of deployment presents certain limitations. The constraints are associated with the incipient phase and small scale of the tests, temporary services, technology maturity, and lack of regulatory and homologation framework.

These limitations reduce the performance and usability of the shuttle. In addition, the demonstrator sites are facing constraints due to Covid 19 pandemic (more details refer to section 4.2). Hence, tests have been facing interruptions, and some sites have limited the maximum numbers of passengers to four, a factor that influences the performance of the environmental indicators negatively, for instance.

In addition, data collection for the WP8 impact assessment has been impacted as a whole. Hence, data availability and data asymmetry among the demonstrator sites pose also some limitations for the sustainability assessment. Also, other proposed indicators are planned to be developed and measured by the end of the project.

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4 The COVID-19 impacts

4.1 The impacts of COVID-19 on mobility

In March 2020, COVID-19 was characterized as a pandemic by the World Health Organization (WHO) (World Health Organization 2021). The pandemic has led to many restrictions that are noticeable in different areas of life. This also includes the mobility sector. According to Heineke et al. (2020) the number of travelled passenger kilometres decreased worldwide by 50 to 60 per cent since the beginning of the crisis. To give an insight into changes in mobility behaviour, different examples will be presented. This comprises analyses from four European cities/regions: Budapest (Hungary), Stockholm (Region) (Sweden), Santander (Spain) and Gdańsk (Poland).

In March 2020, several mobility restrictions were implemented in Budapest, resulting in a 57 % decrease in mobility in the second half of this month, according to a middle estimate. The reduction varies for different modes of transport. The highest decrease in demand can be seen in public transport with around 80% (Bucsky 2020).

The analysis for Stockholm (Region) covers the period from February 2020 to the end of May 2020. In contrast to other countries, Sweden's strategy has been built mostly on recommendations instead of mandatory measures. The results show that in Stockholm (Region), the public ridership for commuter trains and the metro was reduced by around 60 % as of mid of March 2020. As a reference, the same period in 2019 was considered (Jenelius and Cebecauer 2020).

A study by Aloi et al. (2020) from the city Santander in Spain shows the drop of mobility starting with restrictions on mobility in mid of March 2020. The result estimates that the overall mobility has been decreased by 76 % while there are variations depending on daytime. The decrease varies as well depending on the means of transport. Travelling by bus is reduced by 93 % while the drop of car travel is about 68 %. The modal share changed, with an increase of private transport from 48 % to 77 %, while the share of public transport decreased from 8 % to 2 %. Likewise, the share of pedestrian journeys fell from 42 % to 19 %. The analysis also shows that the number of traffic accidents dropped clearly (Aloi et al. 2020).

For the city Gdańsk in Poland, a diagnostic survey method was used to analyse the impact of the pandemic on mobility behaviours (Przybylowski et al. 2021). The focus was on public transport users and on factors that have an influence on the users' feeling of safety and comfort during public transportation. The collected responses from May and June 2020 show that only 9 % of the respondents did not reduce the use of public transport, where 44 % reduced the use of public transport. The remaining 47 % declared not to use public transport. Reasons for reduction include the elimination of the need to travel due to home-office requirements, as well as the fear of COVID-19. However, 74 % of the respondents are open and willing to return to public transport after stabilisation of the COVID-19 situation (Przybylowski et al. 2021).

McKinsey & Company (Heineke et al. 2020) analysed what the main concerns are in the choice of shared micromobility. In comparison to the time before the COVID-19 pandemic for the respondents, the risk of infection became the top concern for commuting and business trips as well as personal trips (Heineke et al. 2020).

In Germany, a comparison of modal split before (end of February 2020) and during the crisis (end of March 2020) shows a decrease in the daily travel distance of 47 % (Mobility Institute Berlin, 2020). This reduction was severe for public transport and long-distance train. Other transportation means, such as cycling (from 2 % to 6 %), walking (from 5 % to 8 %) and using the car (63 % to 69 %), have increased (Mobility Institute

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Berlin 2020). This trend in Germany can't be seen everywhere. For example, in Budapest, both cycling and pedestrian traffic are declined (Bucsky 2020). Nevertheless, a trend towards more cycle paths can be recognized. Citywide policies in Milan, Paris and Brussels plan to turn some kilometres of car lanes into cycle lanes (Heineke et al. 2020).

4.2 The impact of COVID-19 for the deployment of automated minibuses

The COVID-19 pandemic is a major challenge for the mobility sector and especially for public transport. Social distancing, hygienic regulations and the fear or risk of infection have an influence on the use of public transport. As the automated minibuses are intended to supplement the public transport offer, the described impacts apply to them as well. The COVID-19 pandemic also had severe impacts on the AVENUE project. The sites had trials interruptions from March 2020 to May 2020 and October 2020 to May 2021. In some sites as Nordhavn and Ormoya, the passengers' capacity was limited to a maximum of 5 people. The use of protective masks is a requirement, and a low demand for automated minibuses services was registered in the year of 2020.

More details about changes in mobility behaviour are provided by the user survey in Nordhavn (Copenhagen), applied to the users of the automated minibuses from August to December 2020. As illustrated in Figure 10, 53% of the respondents stated that COVID-19 did not influence their mobility behaviour, whereas 29% stated that they altered their transport habits, implying a longer perspective, and 12% stated changes within a short-term perspective. Regarding the type of changes, 81% of the respondents stated that they use less public transport; 11% indicate other changes.

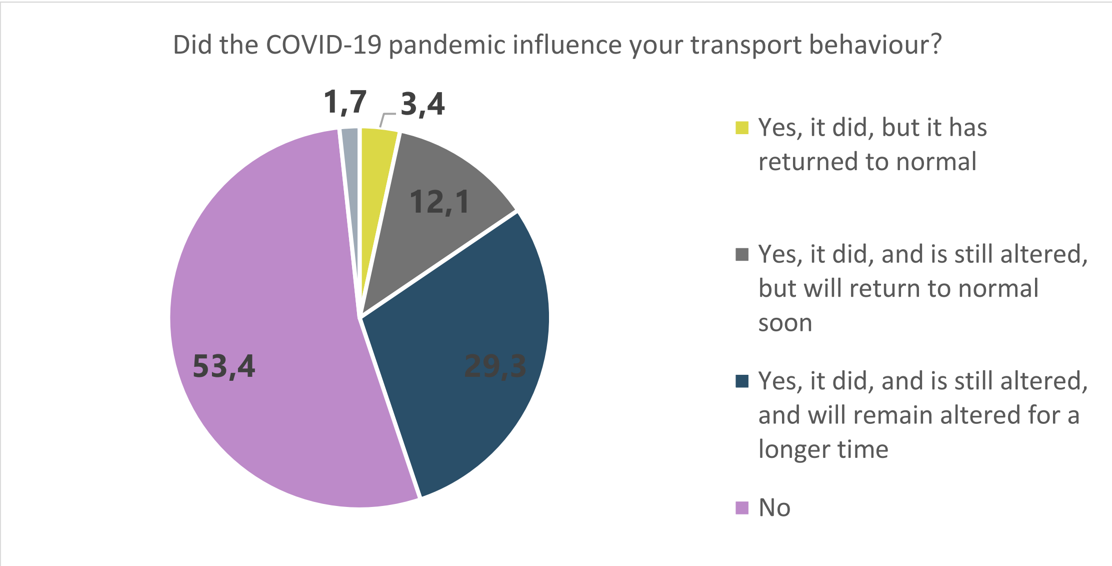

Figure 10. Effects of the COVID 19 pandemic on mobility behaviour (n=58)

Since the start of the COVID-19 pandemic in spring 2020 there is progress in the pandemic response, e.g. through the availability of Rapid Antigen Tests and through the increasing availability of vaccines. These tools can be used to enhance the attractiveness of automated minibuses again, especially in comparison with other means of public transport as trams or normal size buses. One idea would be to include an electronic query into the app while ordering the minibus. With this function, it could be requested and

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controlled that only vaccinated persons or people with a current negative Rapid Antigen Test result could book a ride. Another model for using automated minibuses would be to transport within one minibus only groups of people who are in contact with each other. An example is to transport only students within one minibus to a school or university who will sit in a classroom together or use the minibus as a shuttle for employees who work together in one office. These suggestions are only possible and attractive due to the concept and size of an automated minibus by the AVENUE project, and therefore this concept has benefits compared to some other means of public transport.

These opportunities, where the minibus can be used as a concept adapted to the needs of potential customers, can still be seen as a business case in the time after the pandemic. The study in Gdańsk shows that 74 % of the respondents are open and willing to return to public transport after the stabilisation of the COVID-19 situation (Przybylowski et al. 2021). This means that an increase in the usage rates of the automated minibuses can be expected again, and with the described concepts that are adapted to the needs of passengers, even additional potential passenger groups can be found.

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5 Outlook and conclusions

5.1 Sustainability assessment of future mobility systems

In this deliverable, we presented the intermediate results of the sustainable mobility indicators. The final assessment will be presented in the final AVENUE sustainability assessment, due in April 2022. Several actions are required to finalize the assessment, such as the development of remaining indicators, more data collection and more accurate analysis per pilot site. The final assessment will highlight the current strengths and weaknesses of the automated minibuses performance considering the mobility multi-dimensions.

As a second tier of the sustainability assessment, we will assess the sustainability impacts of possible deployment scenarios. For this assessment, the method of scenario planning helps outline deployment strategies of the automated minibuses in the future. The avoidance costs (externalities savings or costs from introducing the minibuses) provide insights on the recommended strategy to adopt to reduce the environmental deterioration of the transport system and promote sustainable mobility. Accordingly, internalization policies and TDM measures could be implemented in line with the SUMP guidelines.

The results from indicators assessing the current performance of deployment of automated minibuses coupled to the externalities scenarios studies are seen as complementary, and they will underpin recommendations following SUMP concept and guidelines aiming at strategies and planning sustainable urban mobility with automated shuttles. It will also provide the basis for the WP9 focused on recommendations for policies and regulations.

As a first step, we include a summary of the scenario to be analysed on the city level in appendix E. The scenarios presented here rely on a literature review, a deliberative process within the AVENUE team, and representative surveys. As a second step, we will account for the scenario on the pilot level.

The scenarios follow the Intuitive logic approach. It analyses external factors external (economic, political, environmental, technological, and social) that could affect business decisions within private companies. Here, it will be used to determine potential deployment strategies. Part of this method is to determine the driving forces and key factors. Driving forces are critical to defining the deployment efforts, while key factors present general trends of AM introduction.

We fixed the key factors (uncertainties) as follow:

1. whether the automated minibuses are introduced to compete or complement public transport
2. whether the automated minibuses are replacing only one modal share or multiple modal shares

The driving forces are defined as follows:

- Technology advancement;
- urban policy (political agenda for mobility and sustainability);
- transportation offer (use and modes available);
- the users.

The scenarios are going to be assessed qualitatively, based on the literature review and the observations from the stakeholders, on 2 levels. First, we use the intuitive logic method as described earlier. Second, we try to determine the potential consequences (direct and long-term) of the deployment strategy in each scenario. We focus on the impact on the transportation system (on the other modes of transportation and

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consequent modal shifts, on the mobility demand -overall Vkm) and the impact on the infrastructure. This qualitative analysis is supported by the externalities calculations.
Furthermore two scenarios specifically are the backbone for the WP9. The first scenario focuses on the automated minibuses in an integrated transport system and MaaS, it is called AM in ITS. The second provides a reference point as it considers the potential effect of robotaxis as a car-sharing fleet on mobility as well as cities (in form of externalities mostly).
These two scenarios could show contrasting results in term of impact on emissions, energy consumption, congestion, and induced demand. The analysis will prove valuable for cities to opt for which deployment strategy based on their context and the environmental and social goals they desire to achieve.

5.2 Building the strategies and recommendations for the integration of the automated minibuses in urban mobility

The outcomes from the sustainability assessment will provide the building blocks for the WP9 to formulate strategies, recommendations and roadmaps for a beneficial integration of the automated minibuses in urban mobility. A beneficial integration is understood by - a customer and citizen-centric approach, engendering positive externalities for the cities, boosting innovation and cooperation among mobility providers and mobility stakeholders - aiming at offering more efficient and flexible mobility within Mobility-as-a-Service perspective.
MaaS entails the integration of public and private mobility options through a single interface to offer passengers a multi and intermodal trip (Sochor et al. 2018; Kamargianni et al. 2015). The single interface plays an important role to integrate mobility information, booking, payment, ticketing and the real-time status. However, the challenge to offer a full MaaS concerns the standardization of data and interfaces among the different transport operators (Bestmile 2020).
In this regard, the so-called Application Programming Interfaces (APIs) enable authorized applications to communicate, use one another’s functions, and exploit data sets provided by other applications or databases (Matthes and Bondel). On the one hand, the APIs are considered the ‘connective tissue of the cloud’, they are essential to integrate the transport system; on the other hand, the urban mobility ecosystems is very fragmented (Bestmile 2020).
Regarding this barrier, some initiatives envision setting standards of open APIs to enable mobility providers to integrate services. For instance, the projects MyCorridor, MaaS4EU and IMOVE foresee the use of a ‘common language’ to designing a transport service API, comprehending ‘the use of communication protocol and data format to security standards, basic methods and service calls, responses and general behaviour of an API’ (MaaS Aliance 2019). Another initiative, the Information Technology for Public Transport (ITxPT), focuses on open standards and procedures for integrated information and Intelligent Technology Systems (ITS) for public transport (Rogg 2021). Therefore, open interfaces, protocols and standards are key factors for MaaS.
It is worth noting that the rise of open APIs is leading to new business models (Matthes and Bondel). The API economy changes the way organizations cooperate, fostering partnerships among mobility providers and other stakeholders to integrate functionalities, databases and interfaces (Matthes and Bondel).
Therefore, open data and open API are prerequisites for AM interoperability, intermodality and MaaS integration. Such topics and scenarios concerning the automated minibuses within intelligent

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transportation systems (ITS) will be further discussed on WP9, as they will influence the integration of the AM on the mobility system and their compatibility with the intelligent transport system.

5.3 Conclusions

The sustainability impact assessment builds upon a comprehensive approach, embedding the social, environmental and economic inputs from WP8, as well as aspects from technical performance and mobility system integration.

The applied set of indicators assess the current performance and impacts of the automated minibuses, which allows a comparison among the different sites and tracking over time the progress towards goals to achieve more sustainable mobility. The next steps include more data collection on the pilot sites and the measurement of other indicators according to data availability. The WP9 best and worst case scenarios will be integrated as well.

It is worth noting that the small scale of deployment, the newness of the technology and Covid-19 pandemic restrictions posed some limitations to the automated minibuses performance. Hence, the current performance of the automated minibuses does not fulfil all the premises for sustainable mobility. However, the automated minibuses prove to be feasible as new alternative mobility and with the potential to support cities to achieve sustainable mobility under certain conditions (e.g. vehicle usability and occupancy, policies and strategies for implementation, as open data and open API for interoperability, intermodality and overall connected mobility and mobility efficiency). In this regard, the final deliverable on sustainability assessment aims to provide recommendations to strengthen a more environmentally friendly deployment of the automated minibuses and more substantial alignment considering SUMP principles and guidelines.

The perspectives are that the automated minibuses could be integrated into urban mobility to improve the transport network, cover mobility gaps, and foster intermodality by substituting motorised vehicles, offering on-demand and door-to-door services. Indeed, the automated minibuses could support the MaaS approach, electrification, shared mobility, and accordingly to the recommendations in our study. The suggested methodology can help to take better decision of the stakeholders (WP2), take advantage of AM integrated in a Maas or an ITS and foster the acceptance, the sustainable agenda of cities, SUMP and last but not least the EU sustainable and smart mobility strategy..

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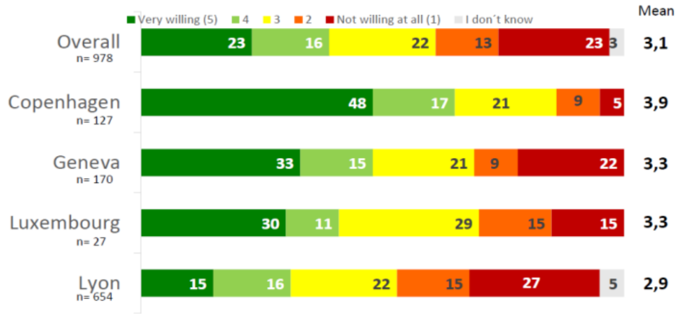
Appendix A:

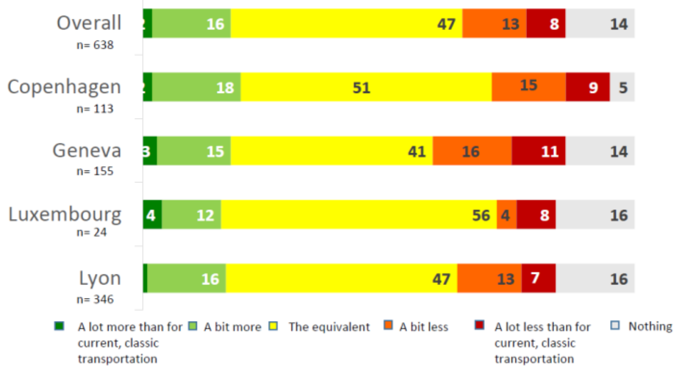
Representative survey – willingness to use the automated minibuses

How willing are you to use autonomous e-minibuses?
Numbers in percent



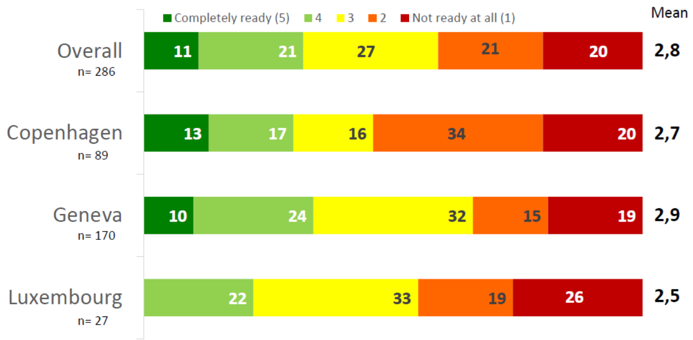
Representative survey - willingness to pay to use the automated minibuses

What would you be willing to pay to use autonomous e-minibuses in general?
Numbers in percent



Representatie survey – perception about the readiness of the technology

In your opinion, is the current technology ready to have autonomous e-minibuses on the public road?
Numbers in percent



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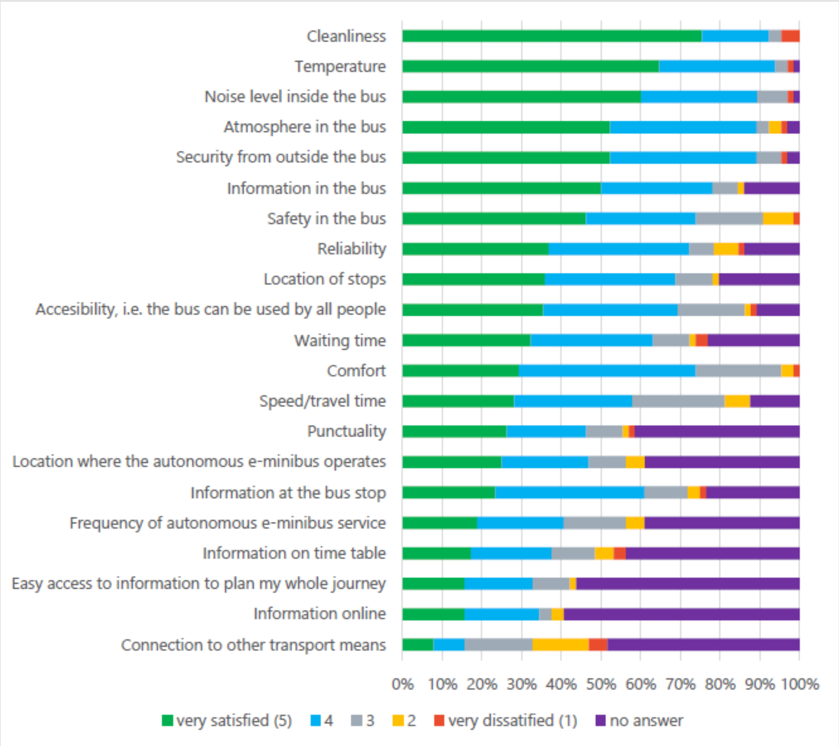
Appendix B

User survey for Norhavn (Copenhagen)

Question about the satisfaction woth the last ride



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Appendix C

Total Cost of Ownership of the AVENUE service

	Luxembourg (Sales-Lentz)		Geneva* (TPG)	Copenhagen/Oslo (Holo)		Lyon (Keolis)	AVERAGE
	Pfaffenthal	Contern	Meyrin	Nordhavn	Ormøya	Décines	Avenue
CAPEX							
Single shuttle							
Fleet total							
OPEX							
Single shuttle							
Fleet total							
KPIs**							
Cost passenger/km							
Cost shuttle/km							

These data are not public

* By being an on-demand site, values for the Belle Idée (Geneva) were not calculated yet.

** Values comprise the Total Cost of Ownership considering the CAPEX, OPEX and Local externalities.

Authors: Antonialli, Mira-Bonnardel, Bulteau (2021), based on D8.4 Second Iteration Economic impact (Antonialli et al. 2021).

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Appendix D

Share of energy from renewable sources in gross electricity consumption, 2004-2018
(%)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
EU-27	15.9	16.4	16.9	17.7	18.6	20.7	21.3	23.3	25.2	26.9	28.7	29.7	30.2	31.1	32.2
EU-28	14.2	14.8	15.3	16.1	16.9	19.0	19.7	21.6	23.5	25.3	27.4	28.8	29.5	30.7	32.1
Belgium	1.7	2.4	3.1	3.6	4.6	6.2	7.1	9.1	11.3	12.5	13.4	15.6	15.9	17.3	18.9
Bulgaria	8.4	8.7	8.7	8.9	9.5	10.9	12.4	12.6	15.8	18.7	18.7	19.0	19.1	19.0	22.1
Czechia	3.7	3.8	4.1	4.6	5.2	6.4	7.5	10.6	11.7	12.8	13.9	14.1	13.6	13.7	13.7
Denmark	23.8	24.6	24.0	25.0	25.9	28.3	32.7	35.9	38.7	43.1	48.5	51.3	53.7	60.0	62.4
Germany	9.5	10.6	12.0	13.8	15.2	17.6	18.3	21.0	23.6	25.3	28.2	30.9	32.3	34.6	38.0
Estonia	0.5	1.1	1.4	1.4	2.0	6.0	10.3	12.2	15.7	12.9	14.0	15.1	15.5	17.4	19.7
Ireland	6.0	7.2	8.5	9.7	10.8	14.0	15.6	18.3	19.8	21.3	23.5	25.5	26.8	30.1	33.2
Greece	7.8	8.2	8.9	9.3	9.6	11.0	12.3	13.8	16.4	21.2	21.9	22.1	22.7	24.5	26.0
Spain	19.0	19.1	20.0	21.7	23.7	27.8	29.8	31.6	33.5	36.7	37.8	37.0	36.6	36.4	35.2
France	13.8	13.7	14.1	14.3	14.4	15.1	14.8	16.2	16.5	17.0	18.5	18.8	19.2	19.9	21.2
Croatia	35.0	35.2	34.8	34.0	33.9	35.9	37.5	37.6	38.8	42.1	45.2	45.4	46.7	46.4	48.1
Italy	16.1	16.3	15.9	16.0	16.6	18.8	20.1	23.5	27.4	31.3	33.4	33.5	34.0	34.1	33.9
Cyprus	0.0	0.0	0.0	0.1	0.3	0.6	1.4	3.4	4.9	6.7	7.4	8.4	8.6	8.9	9.4
Latvia	46.0	43.0	40.4	38.6	38.7	41.9	42.1	44.7	44.9	48.7	51.0	52.2	51.3	54.4	53.5
Lithuania	3.6	3.8	4.0	4.7	4.9	5.9	7.4	9.0	10.9	13.1	13.7	15.5	16.9	18.3	18.4
Luxembourg	2.8	3.2	3.2	3.3	3.6	4.1	3.8	4.1	4.7	5.3	6.0	6.2	6.7	8.1	9.1
Hungary	2.2	4.4	3.5	4.2	5.3	7.0	7.1	6.4	6.1	6.6	7.3	7.3	7.3	7.5	8.3
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.1	1.6	3.3	4.3	5.7	6.8	7.7
Netherlands	4.4	6.3	6.5	6.0	7.5	9.1	9.6	9.7	10.4	9.9	9.9	11.0	12.5	13.8	15.1
Austria	61.6	62.9	63.8	65.7	65.9	68.6	66.4	66.8	67.4	68.9	71.1	71.5	72.5	71.6	73.1
Poland	2.2	2.7	3.0	3.5	4.4	5.8	6.6	8.2	10.7	10.7	12.4	13.4	13.4	13.1	13.0
Portugal	27.4	27.7	29.3	32.3	34.1	37.6	40.6	45.8	47.5	49.1	52.1	52.6	54.0	54.2	52.2
Romania	28.4	28.8	28.1	28.1	28.1	30.9	30.4	31.1	33.6	37.5	41.7	43.2	42.7	42.0	41.8
Slovenia	29.3	28.7	28.2	27.7	30.0	33.8	32.2	31.0	31.6	33.1	33.9	32.7	32.1	32.4	32.3
Slovakia	15.4	15.7	16.6	16.5	17.0	17.8	17.8	19.3	20.1	20.8	22.9	22.7	22.5	21.3	21.5
Finland	26.7	26.9	26.4	25.5	27.3	27.3	27.7	29.4	29.5	30.9	31.4	32.5	32.9	35.2	36.8
Sweden	51.2	50.9	51.8	53.2	53.7	58.3	55.8	59.6	59.8	61.7	63.2	65.7	64.9	65.9	66.2
United Kingdom	2.5	3.2	3.7	4.1	4.7	6.0	6.9	8.3	10.3	13.4	17.5	21.9	24.0	27.4	30.9
Norway	98.0	97.4	100.8	99.1	100.2	105.2	98.2	105.9	104.6	106.9	110.1	106.8	105.7	104.9	106.8
Montenegro	:	39.1	37.7	37.6	38.3	46.6	45.7	41.6	42.8	49.1	51.4	49.6	51.0	50.1	52.4
North Macedonia	14.5	14.0	14.0	13.7	13.8	15.5	15.8	14.8	16.7	18.2	19.3	21.7	24.1	24.8	24.8
Serbia	18.5	22.4	23.6	24.8	25.9	28.3	28.2	27.5	28.5	28.0	30.3	28.9	29.2	27.4	28.7
Albania	70.0	76.1	74.2	79.6	73.3	70.7	74.6	66.1	72.4	62.7	71.0	79.2	82.1	91.0	92.5
Turkey	27.9	26.3	24.7	23.2	22.8	24.7	25.3	25.1	27.1	30.0	30.5	33.2	34.8	35.1	37.5
Kosovo*	0.5	0.6	0.9	1.0	1.0	1.1	1.4	1.4	1.5	1.6	1.9	1.8	4.0	3.6	4.2

Note: ":" means data not available

* *This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo declaration of independence.*

Source: Eurostat (online data code: nrg_ind_ren)

Source: Eurostat (2020)

Not approved yet

Appendix E

List of the AVENUE scenarios to be assessed qualitatively and with externalities calculations

Scenario
Pilot Level
Scenario 0: BAU scenario / control case Keeping the current modal share in the pilot area/city (no electric minibuses on site) ***Scenario 1: Avenue scenario*** Keeping the current modal share in the pilot area with limited operation of 1 or 2 electric minibuses on pilot site ***Scenario 2: Full operation scenario on demand*** Using Full operating electric minibuses on demand (full schedule- full occupancy – optimized use of energy) with no operator on board, to replace the most dominant mode of transport based on the surveys in the site area
city level
Reference: BAU scenario / control case Keeping the current modal share in the city (no electric minibuses on site) ***Scenario 4: Replace buses across the city (no on-demand services)*** Replace buses with automated minibuses ***Scenario 5: expand the transport network (on- demand)*** Serve new areas (no public transportation offered) with automated minibuses - Externalities compared to cars ***Scenario 7: Full targeted operation (Replace buses and expand the transport network on demand)*** replace buses with low route capacity with electric minibuses and introduce automated minibuses to places with no public ***Scenario 8: Laissez-faire , robotaxi:*** Automated vehicles as individual mean of transportation concept Private transport competing with public transport ***Scenario 9: automated minibus in MaaS:*** Full operation Automated minibuses as public transportation feeder in an intermodal city mobility concept ***Scenario 10: Replace all cars in the city*** ***Sceanrio 11: Induced demand – Rebound effect***

Description of selected city-level scenarios

Scenario	modal shifts	Description	references
1 – Replace all buses	Replace standard buses in the city	▪ <u>Driving forces:</u> 1-*Technological development*: - AM platooning, improved sensory capabilities V2X, level 5 automation *2-Urban policy:* - high push for technology and smart cities initiatives, use of mobility innovations *3-transport offer:* - AM fare being cheap - limited introduction of electric buses -Buses are obsolete, no significant innovation in standard buses to improve their environmental effects, not connected to MaaS services - congestion in city centres deter people from using individual mobility, so bus riders will not use cars instead *4-User:* bus riders ▪ <u>Consequences:</u> - mostly replacing monomodal trips by bus - no effect on walking and biking	<u>(Coppola and Morisio 2016; Bimbraw 2015; Leich and Bischoff 2019; Iclodean et al. 2020; Zawieska and Pieriegud 2018; ITF 2017)</u>

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2 - Serves new areas	Replace the car modal share in areas with no PT with AM in suburban and interurban areas in order to expand the PT network	▪ Driving forces: 1-*Technological development:* - higher speeds, on-demand service, level 5/4 automation *2-Urban policy* - increase access on a regional level, - decrease reliance on individual vehicles, - reduce urban development pressure in urban settlement's by facilitating the commute in and outside of cities 3- *transport offer:* - PT limited in suburban areas, reliance on cars *4-User*: - private car owners who are monomodal and travel for long distances (more than 5 km), mainly in suburban areas ▪ Consequences: - No effect on walking or biking - Minibuses might travel with less capacity to provide comfort and save time for passengers (comparable to private cars) - interurban areas become more attractive (urban sprawl)	(Murray et al. 1998; Bernhart et al. 2018; Hinderer et al. 2018; González-González et al. 2020; ITF 2017) (Beukers 2019)
3 - targeted operation of AM	Replace the car share in areas with no PT with AM (scenario 2) and Replace nocturnal buses and empty running buses	▪ Driving forces: 1-*Technological development:* - higher speeds, on-demand service, level 5/4 automation *2-Urban policy* - increase access on a regional level, - decrease reliance on individual vehicles, - reduce urban development pressure in urban settlement's by facilitating the commute in and outside of cities - optimise PT, and reduce costs for public transport operators 3- *transport offer:* - PT limited in suburban areas, reliance on cars *4-User*: - private car owners who are monomodal and travel for long distances (more than 5 km), mainly in suburban areas (remote areas passengers) - night time passengers ▪ Consequences: - No effect on walking or biking - Minibuses might travel with less capacity to provide comfort and save time for passengers (comparable to private cars) - urban sprawl	(Murray et al. 1998; Bernhart et al. 2018; Hinderer et al. 2018; McCallum 2020; Krueger et al. 2016) (Beukers 2019)
4 – AM in MaaS (AM as public transportation feeder in intermodal mobilit	-Based on survey, For now, we estimate the following: -Replace walking trips more than 600 m in intermodal trips -Replace car and biking trips in intermodal trips	▪ Driving forces: 1-*Technological development:* - MaaS platform, improved sensory capabilities V2X, level 5 automation *2-Urban policy* - Strategy to support public transport and increase connectivity - increase accessibility and access, - 0-emission strategy in the city - focus on Smart city initiatives and MaaS solutions - limit access of cars to city centres (fuel and parking measures) - Urban development focused on compact and walkable city 3- *transport offer:*	(Gebhardt et al. 2016; Giansoldati et al. 2020; Kagerbauer et al. 2015; Paydar et al. 2020; Tirachini 2015; Yap et al. 2016; Bimbraw 2015; González-González et al. 2020; Zawieska and Pieriegud 2018)

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y)	-Replace other less used modes of transport (motorcycles)	- emphasis on seamless travel - environmental modes of transport are preferable - strong public transport *4-User*: - Intermodal travellers (last and first mile passengers) ▪ Consequences: - Replace some walking and biking - Increase the attractiveness of cities (effects on real-estate pricing)	
5. replace all cars	Replace cars in the city	Driving forces: *Technological development:* - similar to scenario 1 *2-Urban policy* - similar to scenario 4 - no long-term plan or anticipation for the effect of eliminating individual motorised mobility 3- *transport offer:* - environmental modes of transport are preferable - public transport offer not strong enough to cover the demand for no cars in cities *4-User*: - car drivers ▪Consequences: - better urban planning - better connectivity to city centres	(Fournier et al. 2020; Duarte and Ratti 2018; Medina-Tapia and Robusté 2019; González-González et al. 2020; ITF 2017)

Not approved yet

6 Publication bibliography

Aloi, Alfredo; Alonso, Borja; Benavente, Juan; Cordera, Rubén; Echániz, Eneko; González, Felipe et al. (2020): Effects of the COVID-19 Lockdown on Urban Mobility: Empirical Evidence from the City of Santander (Spain) (9).

Anderson, James M.; Kalra, Nidhi; Stanley, Karlyn D.; Sorensen, Paul; Samaras, Constantine; Oluwatola, Oluwatobi A. (2014): Autonomous vehicle technology. A guide for policymakers. Santa Monica CA: Rand Corporation.

Antonialli, Fabio; Fournier, Guy; Jaroudi, Ines; Mira-Bonnardel, Sylvie; Thalhofer, Michael (2021): D8.2 Second Iteration Economic impact. Available online at https://h2020-avenue.eu/public-delivrables/, checked on 4/20/2021.

Arsenio, Elisabete; Martens, Karel; Di Ciommo, Floridea (2016): Sustainable urban mobility plans: Bridging climate change and equity targets? In *Research in Transportation Economics* 55, pp. 30–39. DOI: 10.1016/j.retrec.2016.04.008.

Bernhart, Wolfgang; Kaiser, Hitoshi; Ohashi, Yuzuru; Schönberg, Tobias; Schilles, Laurianne (2018): Reconnecting the rural Autonomous driving as a solution for non-urban mobility. Roland Berger Focus. ROLAND BERGER GMBH. Frankfurt am Main.

Bestmile (2020): The Critical Role of APIs in Mobility Services. Available online at https://bestmile.com/company-blog/the-critical-role-of-apis-in-mobility-services/, checked on 7/13/2021.

Beukers, J. (2019): First Iteration Geneva Large Scale Pilot Use Case Demonstration Report. TPG. Available online at https://cordis.europa.eu/project/id/769033/results.

Bimbraw, K (Ed.) (2015): Autonomous cars: Past, present and future a review of the developments in the last century, the present scenario and the expected future of autonomous vehicle technologyand Robotics. 12th International Conference on Informatics in Control, Automation, and Roboticis (Automation).

Bischoff, Joschka; Maciejewski, Michal; Nagel, Kai: City-wide shared taxis: A simulation study in Berlin. In : 2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC), Yokohama, Japan, pp. 275–280.

Bösch, Patrick M.; Becker, Felix; Becker, Henrik; Axhausen, Kay W. (2018): Cost-based analysis of autonomous mobility services. In *Transport Policy* 64, pp. 76–91. DOI: 10.1016/j.tranpol.2017.09.005.

Bucsky, Péter (2020): Modal share changes due to COVID-19: The case of Budapest.

Cai, C. (2012): Noise emmision from electric cars. Master's Thesis. Technical University of Denmark.

Chinellato, M.; Morfoulaki, M. (2019): Sustainable urban mobility planning in metropolitan regions. Sustainable urban mobility planning and governance models in EU metropolitan regions. Available online at https://www.ubc-sustainable.net/library/publication/sump-topic-guide-sustainable-urban-mobility-planning-metropolitan-regions.

Coppola, Riccardo; Morisio, Maurizio (Eds.) (2016): Connected Car (49).

Dacko, Scott G.; Spalteholz, Carolin (2014): Upgrading the city: Enabling intermodal travel behaviour. In *Technological Forecasting and Social Change* 89, pp. 222–235. DOI: 10.1016/j.techfore.2013.08.039.

Duarte, Fábio; Ratti, Carlo (2018): The Impact of Autonomous Vehicles on Cities: A Review. In *Journal of Urban Technology* 25 (4), pp. 3–18. DOI: 10.1080/10630732.2018.1493883.

Dudenhöffer, K.; Hause, L. (2012): Sound perceptions of electric vehicles. ATZ worldwide eMagazines.

Eltis (2020): The SUMP Concept. Available online at https://www.eltis.org/mobility-plans/sump-concept.

Not approved yet

EU Science Hub (2016): Step 5: Normalisation. European Commission. Available online at https://ec.europa.eu/jrc/en/coin/10-step-guide/step-5#categorical-scales.

European Commission (2013): ANNEXX 1: A CONCEPT FOR SUSTAINABLE URBAN MOBILITY PLANS. Available online at https://ec.europa.eu/transport/themes/urban/urban-mobility/urban-mobility-package_en.

European Commission (2020a): Emissions in the automotive sector. Available online at https://ec.europa.eu/growth/sectors/automotive/environment-protection/emissions_en.

European Commission (2020b): Sustainable Urban Mobility Indicators (SUMI). Available online at https://ec.europa.eu/transport/themes/urban/urban_mobility/sumi_en.

European Commission (2021): Mobility Strategy. A fundamental transport transformation: Commission presents its plan for green, smart and affordable mobility. Available online at https://ec.europa.eu/transport/themes/mobilitystrategy_en.

European Environment Agency (2016): Transitions towards a more sustainable mobility system. TERM 2016: Transport indicators tracking progress towards environmental targets in Europe. Luxembourg, checked on 3/13/2019.

European Environment Agency (2018): Electric vehicles from life cycle and circular economy perspectives - TERM 2018, checked on 12/18/2018.

European Environment Agency (2019): Emissions of air pollutants from transport. Available online at https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-air-pollutants-8/transport-emissions-of-air-pollutants-8.

European Union Agency for Railways (2020): Report on Railway Safety and Interoperability in the EU. Available online at https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjvxq_K_4nwAhW3_rsIHdO1AdQQFjABegQIBBAD&url=https%3A%2F%2Fwww.era.europa.eu%2Fsites%2Fdefault%2Ffiles%2Flibrary%2Fdocs%2Fsafety_interoperability_progress_reports%2Freport_on_railway_safety_and_interoperability_in_the_eu_2020_en.pdf&usg=AOvVaw3BVXt8t8lESzpd2sCKWMdB, checked on 4/19/2021.

Eurostat (2020): Share of energy from renewable sources in gross electricity consumption, 2004-2018 (%). Available online at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Share_of_energy_from_renewable_sources_in_gross_electricity_consumption,_2004-2018_(%25).png#file.

Fagnant, Daniel J.; Kockelman, Kara (2015): Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. In *Transportation Research Part A: Policy and Practice* 77, pp. 167–181. DOI: 10.1016/j.tra.2015.04.003.

Fournier, Guy; Boos, Adrian; Wörner, Ralf; Jaroudi, Ines; Morozova, Inna; Nemoto, Eliane Horschutz (2020): Substituting individual mobility by mobility on demand using autonomous vehicles - a sustainable assessment simulation of Berlin and Stuttgart. In *IJATM* 20 (4), p. 369. DOI: 10.1504/IJATM.2020.112029.

Friedrich, M.; Hartl, M. (2016): MEGAFON - Modellergebnisse geteilter autonomer Fahrzeugflotten des oeffentlichen Nahverkehrs. Universität Stuttgart, Institut für Strassen- und Verkehrswesen. Stuttgart.

Gärling, Tommy; Schuitema, Geertje (2007): Travel Demand Management Targeting Reduced Private Car Use: Effectiveness, Public Acceptability and Political Feasibility. In *J Social Issues* 63 (1), pp. 139–153. DOI: 10.1111/j.1540-4560.2007.00500.x.

Gebhardt, Laura; Krajzewicz, Daniel; Oostendorp, Rebekka; Goletz, Mirko; Greger, Konstantin; Klötzke, Matthias et al. (2016): Intermodal Urban Mobility: Users, Uses, and Use Cases. In *Transportation Research Procedia* 14 (2), pp. 1183–1192. DOI: 10.1016/j.trpro.2016.05.189.

Not approved yet

Giansoldati, Marco; Danielis, Romeo; Rotaris, Lucia (2020): Train-feeder modes in Italy. Is there a role for active mobility? In *Research in Transportation Economics* 2247 (1), p. 100990. DOI: 10.1016/j.retrec.2020.100990.

González-González, Esther; Nogués, Soledad; Stead, Dominic (2020): Parking futures: Preparing European cities for the advent of automated vehicles. In *Land Use Policy* 91 (1), p. 104010. DOI: 10.1016/j.landusepol.2019.05.029.

Gorham, R. (2009): Demystifying Induced Travel Demand. Sustainable Urban Transport Technical Document #. BMZ. Eschborn.

Guldmann, S.; Zinckernagel, C.; Lytzen, P. (2019): D7.7 First iteration Copenhagen Large Scale Pilot Use Case Demonstration report. Amobility. Available online at https://cordis.europa.eu/project/id/769033/results.

Hazan, J.; Lang, N.; Chua, J.; Doubara, X.; Steffens, T.; Ulrich, P. (2016): Will Autonomous Vehicles Derail Trains? BCG. Available online at https://www.bcg.com/publications/2016/transportation-travel-tourism-automotive-will-autonomous-vehicles-derail-trains.

Heineke, Kersten; Kloss, Benedikt; Scurtu, Darius (2020): The future of micromobility: Ridership and revenue after a crisis. In *McKinsey & Company*, 7/16/2020. Available online at https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-future-of-micromobility-ridership-and-revenue-after-a-crisis, checked on 4/16/2021.

Hinderer, Henning; Stegmuller, Jonas; Schmidt, Jannick; Sommer, Jessica; Lucke, Jennifer (Eds.) (2018): Acceptance of Autonomous Vehicles in Suburban Public Transport. 2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC). IEEE.

Huber, D.; Viere, T.; Nemoto, E. H. (2019): First Iteration Environmental Impact. Hochschule Pforzheim.

Iclodean, Calin; Cordos, Nicolae; Varga, Bogdan Ovidiu (2020): Autonomous Shuttle Bus for Public Transportation: A Review. In *Energies* 13 (11), p. 2917. DOI: 10.3390/en13112917.

International Energy Agency (2020): GHG intensity of passenger transport modes, 2019. Available online at https://www.iea.org/data-and-statistics/charts/ghg-intensity-of-passenger-transport-modes-2019.

ITF (2017): Shared Mobility Simulations for Helsinki. Case-Specific Policy Analysis. OECD.

Jenelius, Erik; Cebecauer, Matej (2020): Impacts of COVID-19 on public transport ridership in Sweden: Analysis of ticket validations, sales and passenger counts.

Jochem, Patrick; Doll, Claus; Fichtner, Wolf (2016): External costs of electric vehicles. In *Transportation Research Part D: Transport and Environment* 42, pp. 60–76. DOI: 10.1016/j.trd.2015.09.022.

Jones, E. C.; Leibowicz, B. D. (2019): Contributions of shared autonomous vehicles to climate change mitigation. In *Transportation Research Part D: Transport and Environment* 72, pp. 279–298. DOI: 10.1016/j.trd.2019.05.005.

Kagerbauer, Martin; Hilgert, Tim; Schroeder, Ole; Vortisch, Peter (Eds.) (2015): Household Travel Survey of Intermodal Trips – Approach, Challenges and Comparison (11).

Kamargianni, Maria; Matyas, Melinda; Li, Weibo; Schäfer, Andreas (2015): Feasibility Study for “Mobility as a Service” concept in London.

Korbee, Dorien; Naderer, Gabriele; Dubielzig, Markus; Mathe, Linda; Helfer, Laurent (2021): Deliverable 8.7 Second iteration social impact assessment. AVENUE project. Available online at https://h2020-avenue.eu/public-delivrables/, checked on 3/22/2021.

Krueger, Rico; Rashidi, Taha H.; Rose, John M. (2016): Preferences for shared autonomous vehicles. In *Transportation Research Part C: Emerging Technologies* 69, pp. 343–355. DOI: 10.1016/j.trc.2016.06.015.

Not approved yet

Leich, Gregor; Bischoff, Joschka (2019): Should autonomous shared taxis replace buses? A simulation study. In *Transportation Research Procedia* 41, pp. 450–460. DOI: 10.1016/j.trpro.2019.09.076.

Lelong, J.; Michelet, R. (Eds.) (2001): Passenger cars. Power unit and tyre-road noise, driving behaviour: what are the stakes? Inter-noise. The Hague.

Lim, Hazel; Taeihagh, Araz (2018): Autonomous Vehicles for Smart and Sustainable Cities: An In-Depth Exploration of Privacy and Cybersecurity Implications. In *Energies* 11 (5), p. 1062.

Litman, T. (2019): Well Measured. Developing Indicators for Sustainable and Livable Transport Planning. Victoria Transport Policy Institute. Available online at https://www.vtpi.org/wellmeas.pdf.

Litman, Todd (2021): Transportation Affordability. Evaluation and Improvement Strategies. Victoria Transport Policy Institute. Available online at https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiM2JOa5IrwAhWLLewKHQoiChkQFjABegQIBRAD&url=http%3A%2F%2Fwww.vtpi.org%2Faffordability.pdf&usg=AOvVaw2Zd37pD10b3PF-ztm6FZvw, checked on 4/19/2021.

MaaS Aliance (2019): EU projects explore common standard for digital mobility services. Available online at https://maas-alliance.eu/2019/01/24/eu-projects-explore-common-standard-for-digital-mobility-services/, checked on 7/14/2021.

Marbjerg, Gerd (2013): Noise from electric. a literature survey. Vejdirektoratet. Available online at https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiG37W-1LHtAhUJhRoKHT1KDQ4QFjADegQIBRAC&url=https%3A%2F%2Fwww.vejdirektoratet.dk%2Fapi%2Fdrupal%2Fsites%2Fdefault%2Ffiles%2Fpublications%2Fnoise_from_electric_vehicles_0.pdf&usg=AOvVaw1ksLoAa2OmmfiYsj1WTR_O.

Matthes, Florian; Bondel, Gloria: TP2.1: API Economy and API Ecosystems. Available online at https://tum-llcm.de/en/project/ap2/tp21/, checked on 7/13/2021.

McCallum, Ellyse (2020): How to Improve Public Transportation in Rural Areas. Liftango. Available online at https://www.liftango.com/blog/how-to-improve-public-transportation-in-rural-areas#:~:text=Modify%20inefficient%20fixed%2Droute%20transit,retail%20locations%20and%20employment%20opportunities.

Medina-Tapia, Marcos; Robusté, Francesc (2019): Implementation of Connected and Autonomous Vehicles in Cities Could Have Neutral Effects on the Total Travel Time Costs: Modeling and Analysis for a Circular City. In *Sustainability* 11 (2), p. 482. DOI: 10.3390/su11020482.

Mobility Institute Berlin (2020): Beyond the immediate crisis: The SARS-CoV-2 pandemic and public transport strategy. A Guideline for Action. Available online at https://mobilityinstitute.com/en/publications/new-sars-cov-2-strategy-paper.

Mobility Plans (n.d.): Sustainable Urban Mobility Plans – Planning for people. Available online at https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwim8sX85_rsAhVi8uAKHdkcDkEQFjACegQIAxAC&url=http%3A%2F%2Fwww.rupprecht-consult.eu%2Fuploads%2Ftx_rupprecht%2FSUMP_Brochure_final.pdf&usg=AOvVaw0_usuHRNAt4WzXZqG5xebM.

Mourad, Abood; Puchinger, Jakob; Chu, Chengbin (2019): Owning or sharing autonomous vehicles: comparing different ownership and usage scenarios. In *Eur. Transp. Res. Rev.* 11 (1). DOI: 10.1186/s12544-019-0370-8.

Mück, Matthias; Helf, Christoph; Lindenau, Miriam (Eds.) (2019): Urban living labs fostering sustainable mobility planning in Munich (41).

Murray, Alan T.; Davis, Rex; Stimson, Robert J.; Ferreira, Luis (1998): Public Transportation Access. In *Transportation Research Part D: Transport and Environment* 3 (5), pp. 319–328. DOI: 10.1016/S1361-9209(98)00010-8.

Not approved yet

Nemoto, Eliane Horschutz; Issaoui, Roukaya; Korbee, Dorien; Jaroudi, Ines; Fournier, Guy (2021): How to measure the impacts of shared automated electric vehicles on urban mobility. In *Transportation Research Part D: Transport and Environment* 93, p. 102766. DOI: 10.1016/j.trd.2021.102766.

OECD (2001): Glossary of statistical terms. AVOIDANCE COSTS. OECD. Available online at https://stats.oecd.org/glossary/detail.asp?ID=146#:~:text=Avoidance%20costs%20are%20actual%20or,generally%20pressure%20on%20the%20environment.

Paydar, Mohammad; Fard, Asal Kamani; Khaghani, Mohammad Mehdi (2020): Walking toward Metro Stations: the Contribution of Distance, Attitudes, and Perceived Built Environment. In *Sustainability* 12 (24), p. 10291. DOI: 10.3390/su122410291.

Przybylowski, Adam; Stelmak, Sandra; Suchanek, Michal (2021): Mobility Behaviour in View of the Impact of the COVID-19 Pandemic—Public Transport Users in Gdansk Case Study (1).

Reisch, M. (2019): D7.10 First Iteration Luxembourg Large Scale Pilot Use Case Demonstration Report. Sales-Lenz. Available online at https://cordis.europa.eu/project/id/769033/results.

Rogg, Johannes (2021): White Paper: ITxPT and Information Technology Standards for Public Transport. Delivering flexible, advanced Intelligent Transport Systems through Open Standards. Trapeze Group. Available online at https://trapezegroup.co.uk/itxpt-technical-white-paper/?utm_source=Email+marketing&utm_medium=email&utm_campaign=IT+-+industry+Insight+-+E-mobility+-+Trapeze+Group+-+09+July+2021&utm_term=Read+our+latest+Transport+Tech+Industry+Insight&utm_content=https%3a%2f%2femails.intelligenttransport.com%2frussellpublishinglz%2f&gator_td=MYOPaxduAAShzmyuCrZFtBL0rc3UKIX7gIrZeKyipk9sAOGS7ajoOkC1Ii7wzNnICooBw1Cf7rYkn1CPBkxjdwZuFxAt0kbvcukaWd%2fDPIePpGLZRb5lEnM1Mx%2bBO7yoldDwU7d5B095%2byCInpINxGnari%2bfbDc14U0gPtFDfQjs35%2bY0Ef9qM9k2lJzjCZ9TTpXdEoytTa%2f%2bIFgYFQhcfLgplKZGBMsQAZxtNDwmo8rdzDStOuo2DLtsi6JmpwX, checked on 7/13/2021.

Rupprecht Consult (2019): Guidelines for Developing and Implementing a Sustainable Urban Mobility Plan. Available online at https://www.eltis.org/mobility-plans/sump-guidelines.

SAE (2021): AVSC Best Practice for Metrics and Methods for Assessing Safety Performance of Automated Driving Systems (ADS). Available online at https://www.sae.org/standards/content/avsc00006202103/preview/.

Saisana, Michaela; Becker, William; Neves, Ana Rita; Alberti, Valentina; Dominguez Torreiro, Marcos (2019): Your 10-Step Pocket Guide to Composite Indicators & Scoreboards. Joint Research Centre, European Commission. Available online at https://knowledge4policy.ec.europa.eu/publication/your-10-step-pocket-guide-composite-indicators-scoreboards_en, checked on 4/14/2021.

Sampaio, Carlos; Macedo, Eloísa; Coelho, Margarida C.; Bandeira, Jorge M. (Eds.) (2020): Economic and environmental analysis of measures from a Sustainability Urban Mobility Plan – Application to a small sized city (48).

Shaheen, Susan; Chan, Nelson (2016): Mobility and the Sharing Economy: Potential to Facilitate the First- and Last-Mile Public Transit Connections. In *built environ* 42 (4), pp. 573–588. DOI: 10.2148/benv.42.4.573.

Shen, Li-Yin; Jorge Ochoa, J.; Shah, Mona N.; Zhang, Xiaoling (2011): The application of urban sustainability indicators – A comparison between various practices. In *Habitat International* 35 (1), pp. 17–29. DOI: 10.1016/j.habitatint.2010.03.006.

Sochor, Jana; Arby, Hans; Karlsson, I. MariAnneC.; Sarasini, Steven (2018): A topological approach to Mobility as a Service: A proposed tool for understanding requirements and effects, and for aiding the integration of societal goals. In *Research in Transportation Business & Management* 27, pp. 3–14. DOI: 10.1016/j.rtbm.2018.12.003.

Not approved yet

Soteropoulos, Aggelos; Berger, Martin; Ciari, Francesco (2019): Impacts of automated vehicles on travel behaviour and land use: an international review of modelling studies. In *Transport Reviews* 39 (1), pp. 29–49. DOI: 10.1080/01441647.2018.1523253.

Taiebat, Morteza; Brown, Austin L.; Safford, Hannah R.; Qu, Shen; Xu, Ming (2018): A Review on Energy, Environmental, and Sustainability Implications of Connected and Automated Vehicles. In *Environmental science & technology* 52 (20), pp. 11449–11465. DOI: 10.1021/acs.est.8b00127.

The Federal Council (2019): 68% de l'électricité consommée en Suisse provient des énergies renouvelables. Available online at https://www.admin.ch/gov/fr/accueil/documentation/communiques.msg-id-74577.html.

Tirachini, Alejandro (2015): Probability distribution of walking trips and effects of restricting free pedestrian movement on walking distance. In *Transport Policy* 37 (1), pp. 101–110. DOI: 10.1016/j.tranpol.2014.10.008.

TUMI (2018): Transport demand management. Push and Pull. TUMI. Available online at https://www.transformative-mobility.org/publications/transport-demand-management-push-and-pull.

TUMI (2021): TUMI's Mobility Actions around the World. Available online at https://www.transformative-mobility.org/campaigns/2nd-global-urban-mobility-challenge.

United Nations (1997): Glossary of Environment Statistics. Studies in Methods. United Nations. New York (F, 67).

United Nations (2015): The 17 Sustainable Development Goals. United Nations. Available online at https://sdgs.un.org/goals.

van Essen H.P.; Boon B.H.; Schroten A.; Otten M. (2008): Internalisation measures and policy for the external cost of transport. Produced within the study Internalisation Measures and Policies for all external cost of Transport (IMPACT) – Deliverable 3.

Verbruggen, H., Kuik O. (1991): Indicators of sustainable development: an overview. Kuik O., Verbruggen H. (eds) In Search of Indicators of Sustainable Development.: Springer (vol 1.), checked on 3/5/2019.

Viere, T.; Nemoto, E. H.; Jaroudi, I.; Korbee, D.; Wilhem, J. (2021): D8.2 Second Iteration Environmental Impact. Pforzheim University. Available online at https://cordis.europa.eu/project/id/769033.

WBCSD (2015): Methodology and indicator calculation method for sustainable urban mobility. Available online at https://www.eltis.org/sites/default/files/trainingmaterials/smp2.0_sustainable-mobility-indicators_2ndedition.pdf.

Williams, M.; Minjares, R. (2016): A technical summary of Euro 6/VI vehicle emission standards. The International Council on Clean Transportation. Available online at https://theicct.org/publications/technical-summary-euro-6vi-vehicle-emission-standards.

World Business Council for Sustainable Development (2015): Methodology and Indicators for Sustainable Urban Mobility. Sustainable Mobility Project 2.0 (SMP2.0). Edited by WBCSD, checked on 11/15/2018.

World Health Organization (2021): WHO Director-General's opening remarks at the media briefing on COVID-19 - 11 March 2020. Available online at https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020, updated on 4/14/2021, checked on 4/16/2021.

Yap, Menno D.; Correia, Gonçalo; van Arem, Bart (2016): Preferences of travellers for using automated vehicles as last mile public transport of multimodal train trips. In *Transportation Research Part A: Policy and Practice* 94 (Part B), pp. 1–16. DOI: 10.1016/j.tra.2016.09.003.

Zawieska, Jakub; Pieriegud, Jana (2018): Smart city as a tool for sustainable mobility and transport decarbonisation. In *Transport Policy* 63 (20), pp. 39–50. DOI: 10.1016/j.tranpol.2017.11.004.

Not approved yet

Zinckernagel, Chrisitan (2021): D7.8 Second Iteration Copenhagen Large Scale Pilot Use Case Demonstration Report. Available online at https://cordis.europa.eu/project/id/769033.

Zuttre, Q. (2019): First iteration Keolis Lyon Large Scale Pilot Use Case Demonstration Report. Keolis Lyon. Available online at https://cordis.europa.eu/project/id/769033/results.